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Effects of Propeller Slipstream and Tail Position on the Vibration Characteristics of the Lockheed Lodestar

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ABSTRACT

Flight tests of the Lockheed Lodestar revealed excessive vibration in the cabin. Exhaustive tests proved beyond a doubt that the source of the vibration was aerodynamic in nature, specifically, an interference condition between the propeller slipstream and the stabilizer. Surveys of the flow at the tail indicated that at cruising engine speeds, in level flight, the slipstream just bordered on the horizontal stabilizer and created a vibration in the tail unit which was transmitted into the fuselage. Various changes were made in the airplane in an attempt to remedy this condition and finally, by elevating the tail unit one foot above its previous position, the vibration was entirely eliminated.

INTRODUCTION

MEASUREMENTS made during flight tests of the Lodestar indicated an unpredictable vibration in the cabin of the airplane, sufficient to cause considerable passenger discomfort. This was rather surprising inasmuch as the vibration characteristics of the engine-propeller combination were quite definitely established and were known to be satisfactory. During preliminary tests, the following conclusions were reached:

(1) The predominating vibration in the cabin was vertical.

(2) The vibration increased with distance from the main wing beam. The main beam in this airplane is near the front of the passenger cabin. The vibration at this point was quite reasonable, while in the rear of the fuselage it was excessive.

(3) The vibration was a maximum in the cruising range, *i.e.*, in level flight at engine speeds ranging from 1600 to 2000 engine r.p.m.

(4) The peak vibration frequencies were equal to three times propeller r.p.m. (twice engine r.p.m. for the 3:2 gear ratio). Fig. 1 illustrates this. It also illustrates that no other multiple of this frequency is of great significance. It will be noted that the vibration ordinate is in terms of decibels. The sound analyzer level readings used in plotting the vibration curves have the following actual value of vibration velocity in average inches per second, 100 db. = 1, 80 db. = 0.1, 60 db. = 0.01, 40 db. = 0.001. The measurements were made on a structural member in the rear of the fuselage near the stabilizer attachment bulkhead.

(5) The amplitude of the vibration was related to the power output of the engines. Fig. 2 illustrates that at constant r.p.m. and airspeed, the vibration increases with manifold pressure (power).

(6) The amplitude of vibration was influenced by airspeed. Fig. 3 illustrates that at constant r.p.m. for cruising, the amplitude builds up to a maximum at an indicated airspeed of 150 m.p.h. and falls off at either higher or lower speeds.

(7) It was suspected that the vibration was traceable to some aerodynamic source. The reasoning behind this was that in rough air it was noticed that the vibration at times would be considerably reduced. Furthermore, power sideslips caused a very appreciable reduction in the intensity of the vibration. Slips to the left were more effective than slips to the right. It was found

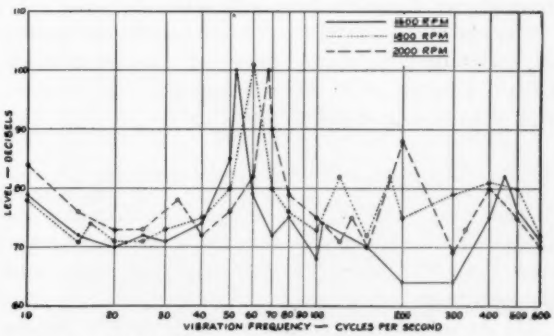

FIG. 1. Vibration measurements with original tail. P.&W. S1E2G Hornet engines; altitude, 8000 feet; power, climb position.

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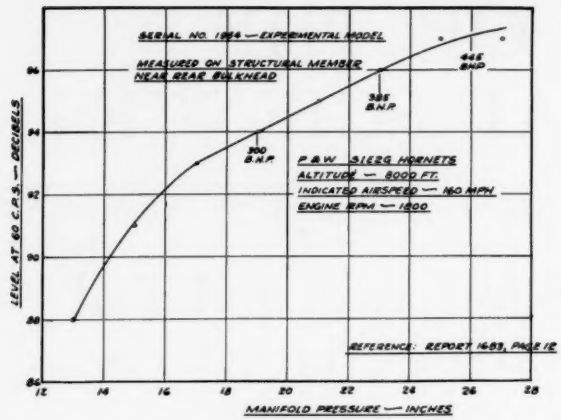
SERIAL NO. 1884 — EXPERIMENTAL MODEL
MEASURED ON STRUCTURAL MEMBER NEAR REAR BULKHEAD
445 B.H.P.
385 B.H.P.
300 B.H.P.
P&W S1E2G HORNETS
ALTITUDE — 8000 FT.
INDICATED AIRSPEED — 160 MPH
ENGINE RPM — 1800
REFERENCE: REPORT 1483, PAGE 12
LEVEL AT 60 C.P.S. — DECIBELS
MANIFOLD PRESSURE — INCHES

FIG. 2. Effect of power on amplitude of vibration.

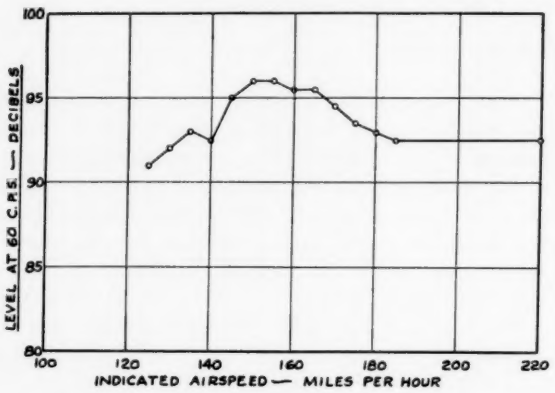

FIG. 3. Effect of airspeed on amplitude of vibration; P.&W. S1E3G Hornet engines; altitude, 8000 feet; 1800 r.p.m.; power, climb position.

that extending the flaps 10 per cent practically eliminated the vibration.

(8) The tests with one propeller feathered indicated that the left engine was responsible for the greatest percentage of the vibration. This supported the theory that the source of the vibration was aerodynamic and pointed to the slipstream as being the cause, inasmuch as the slipstream rotation is the only major aerodynamic dissymmetry about the longitudinal axis.

The above points were quite well established during the preliminary flights and provided clues upon which a flight program could be formulated to trace the vibration to its source and eliminate it.

PROBABLE SOURCE OF VIBRATION

Numerous theories were advanced concerning the ultimate source of the vibration and it was necessary to analyze each. Among the first suggested causes were the following:

(1) An interference caused by the propellers passing in close proximity to the fuselage. As each blade passes within a few inches of the fuselage it enters a region of disturbed airflow and hence its thrust and torque are momentarily altered. This would produce impulses on the propeller shaft of frequency equal to propeller r.p.m. × no. of blades, in this case three times propeller r.p.m. However, previous experience with the Lockheed Model "14" indicated that this condition could be alleviated by counteracting the vibration by means of second order engine unbalance. This is accomplished by indexing the propeller with respect to the position of the master rod cylinder on engines which have a 3:2 gear ratio. This was done on the Lodestar but the vibration was still excessive.

(2) In connection with this same thought was the theory that possibly the propeller-fuselage interference resulted in vibration of the skin adjacent to the propeller disc and this was structure-borne back into the cabin. The fallacy here was that the predominating vibration would then have been lateral instead of vertical, as the tests indicated.

(3) Another possibility was that the propellers, by virtue of their location ahead of the wing, were operating in a field of upflow and hence the blades were subjected to a change in angle of attack throughout a revolution. This would have produced a vibration of the proper frequency, if any. It could also account for the fact that lowering the wing flaps reduced the vibration by markedly changing the wing angle of attack.

(4) The effect of propeller dynamic unbalance was dismissed at once as this would have given rise to a vibration of propeller r.p.m. frequency. The propellers were put in dynamic balance for all tests, however, to eliminate any such effects.

(5) The possibility that second order engine or engine accessory unbalance was responsible naturally was considered seriously but was dismissed in favor of the aerodynamic effects.

(6) Another possibility was that the combined effect of a pulsating slipstream and a wing-fuselage burble resulted in a wake disturbance striking the tail and setting up a vibration period related to the propeller speed.

(7) Along the same line of thought was the idea that the slipstream was acting as a carrier for periodic disturbances from such protuberances as the windshield rain deflector, the carburetor scoop, the oil radiator scoop, etc.

(8) Seemingly the most logical cause, but also the most difficult to remedy, was the idea that the propeller slipstream was impinging on the tail thereby creating tail vibration which was structure-borne to the fuselage. This vibration could be accounted for in at least two ways. The slipstream could cause changes in angle of attack or impact pressure at the stabilizer, thereby changing the tail load, or it could set up a vibration in the elevator. This alters the tail load or, by general buffeting, a local vibration of the tail structure can be developed and transmitted to the fuselage.

Several of the above possibilities were eliminated on one flight. The windshield deflectors were removed

with no effect. Likewise the oil radiator air scoops and the carburetor scoops were found to have no importance. To isolate the effect of elevator vibration, the airplane was deliberately trimmed very nose heavy and tail heavy in turn, the out-of-trim being overcome by the pilot. This procedure, by changing the cable loading, affected the natural control system period, but no effect on the general vibration was noted.

It became more apparent with each flight that complete information concerning the wing wake and its relation to the flow at the tail was needed.

Studies of the Flow at the Tail

A pitot-static rake was installed ahead of the leading edge of the stabilizer such that, at four spanwise stations, a vertical traverse, covering a distance of one foot above the stabilizer to one foot below, could be made. The instrument setup is illustrated in Fig. 4. Pertinent

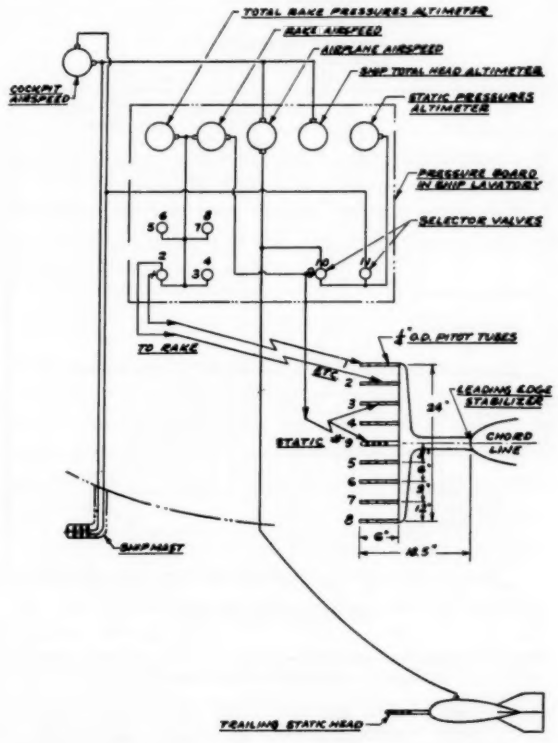

Fig. 4. Instrumentation for pitot-static rake.

installation data can be obtained from Figs. 5 and 6. The instruments were selected so that total and dynamic pressure could be measured at the nose of the airplane (for reference purposes) and at the tail. Static pressure could be measured at the normal airplane pitot-static tube, at the tail, and in the undisturbed stream. It so happened that the dynamic pressure variation ahead of the leading edge of the stabilizer yielded the most important information and was the easiest quantity to measure accurately. This was done by using a sensitive airspeed indicator connected to the rake pitot-static tubes. The pressure distribution curves shown are plots of this airspeed indicator reading against vertical position with respect to the stabilizer chord line.

The test equipment was located in the rear compartment of the fuselage so that the observer could correlate pressure measurements during the various flight conditions with vibration "feel."

Quantitative measurements were made with vibration pick-ups mounted in the tail of the fuselage. Several flight conditions were investigated, namely:

(1) Climb at 2100 r.p.m.;
(2) climb at 1600 r.p.m.;

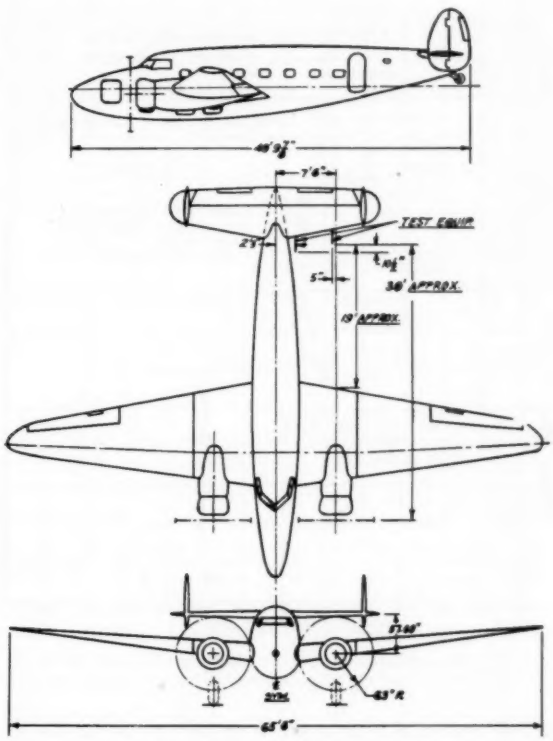

Fig. 5. Location of pitot-static rake.

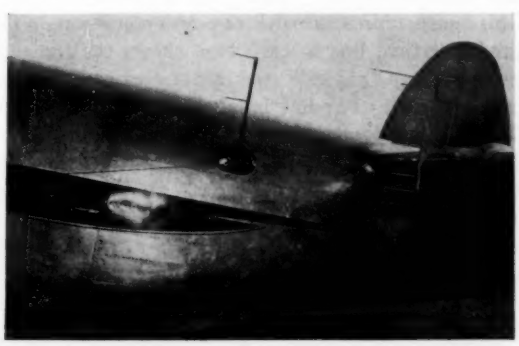

Fig. 6. Pitot-static rake on stabilizer, and hot-wire rake; original tail position.

(3) level flight at 1500 r.p.m.;
(4) level flight at 1800 r.p.m.;
(5) level flight at 2150 r.p.m.;
(6) power glide with 10 per cent flaps at 1500 r.p.m. and the same speed as (3);
(7) constant power at 1800 r.p.m. and at several airspeeds;
(8) single engine operation on each engine.

Fig. 7 is a typical example of the information obtained from the surveys of dynamic pressure ahead of the stabilizer. It will be noted that vertical traverses were

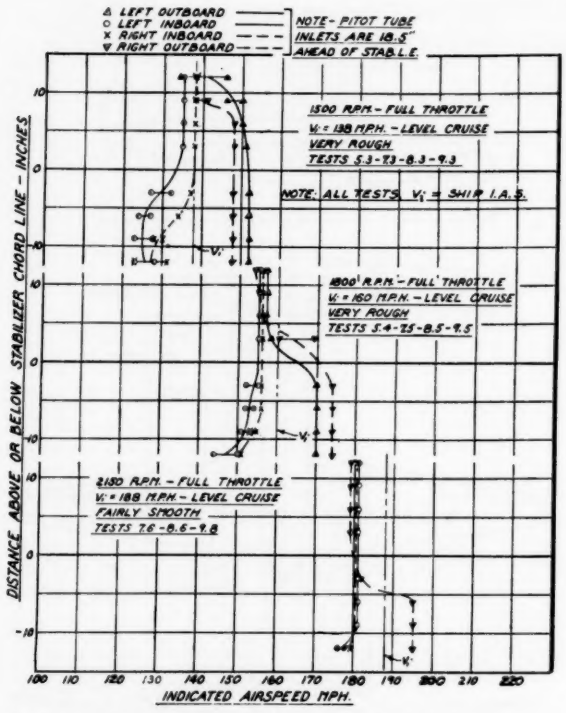
Δ LEFT OUTBOARD
○ LEFT INBOARD
× RIGHT INBOARD
▽ RIGHT OUTBOARD
NOTE- PITOT TUBE INLETS ARE 18.5" AHEAD OF STAB. L.E.
1500 R.P.M. - FULL THROTTLE
V_i = 138 M.P.H. - LEVEL CRUISE
VERY ROUGH
TESTS 5.3-7.3-8.3-9.3
NOTE: ALL TESTS, V_i = SHIP I.A.S.
1800 R.P.M. - FULL THROTTLE
V_i = 150 M.P.H. - LEVEL CRUISE
VERY ROUGH
TESTS 5.4-7.5-8.5-9.5
2150 R.P.M. - FULL THROTTLE
V_i = 188 M.P.H. - LEVEL CRUISE
FAIRLY SMOOTH
TESTS 7.6-8.6-9.8
DISTANCE ABOVE OR BELOW STABILIZER CHORD LINE - INCHES
INDICATED AIRSPEED M.P.H.

FIG. 7. Impact pressure survey showing effect of power on airflow in level cruise; Lockheed Model 18 stabilizer.

at four spanwise locations, one on each side of, and near, the fuselage and one approximately behind each propeller shaft center line. Three sets of curves are shown in this figure, representing three power conditions. The straight vertical line in each case shows the dynamic pressure in m.p.h. as indicated by the airspeed indicator of the airplane. The line is labeled V_i. For absolute value of the impact pressure, a correction must be applied for location error of the airplane pitot-static tube. The four curves in each case indicate the vertical variation in dynamic pressure over the pitot rake. Referring first to the bottom curves, it will be noted that for the outboard station, the individual curve veers sharply to the right at a distance 5 inches below the chord line. This is a definite indication that the slipstream borders there, and that the slipstream velocity is 15 m.p.h. greater than that of the airplane. Referring next to the curves for 1500 r.p.m. in the same figure, it is seen that the curves for the station near the fuselage bend to the left at a point 3 inches below the chord line. This reduction of dynamic pressure indicates the presence of the wake, the fluctuations indicating turbulence. Further study is centered mainly on the location of the slipstream and the wake.

Fig. 8 illustrates conclusively the connection between slipstream position and the magnitude of the vibration. The upper curves show that the slipstream was definitely hitting the tail and the vibration measurements indicated excessive roughness. The lower curves represent the conditions when the flaps were extended 10 per cent of their total travel. It is significant that the smooth flow over the tail was coincident with absence of vibration. Fig. 9 proves that the vibration is excessive when the slipstream borderline is close to the

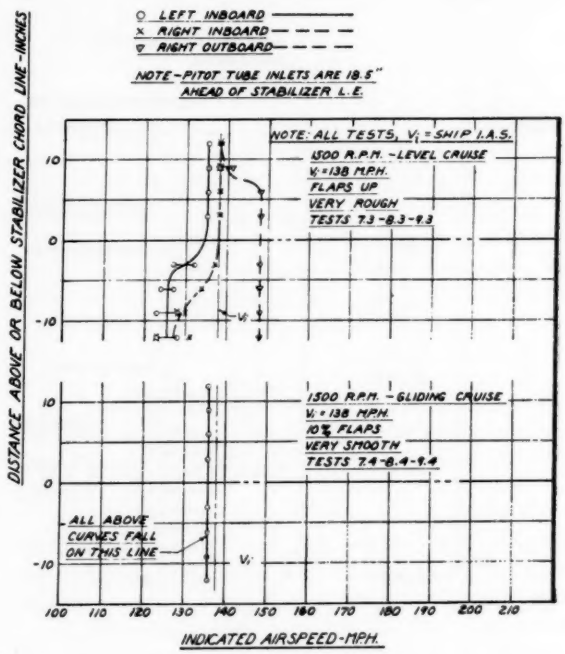

FIG. 8. Impact pressure survey showing effect of wing flaps on airflow; Lockheed Model 18 stabilizer.

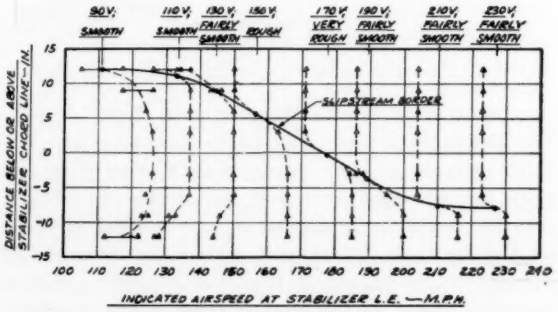
90 V_i SMOOTH
110 V_i SMOOTH
130 V_i FAIRLY SMOOTH
150 V_i ROUGH
170 V_i VERY ROUGH
190 V_i FAIRLY SMOOTH
210 V_i FAIRLY SMOOTH
230 V_i FAIRLY SMOOTH
SLIPSTREAM BORDER
DISTANCE BELOW OR ABOVE STABILIZER CHORD LINE-IN.
INDICATED AIRSPEED AT STABILIZER L.E. — M.P.H.

FIG. 9. Effect of airspeed on slipstream location. Pressure rake on left outboard side; Lockheed Model 18 stabilizer; 1800 r.p.m.

stabilizer. These results provide an explanation for Fig. 3, previously mentioned. Fig. 9 suggests that, if the stabilizer were elevated to a position one foot above the original location, then for all normal cruise, climb, and high speed conditions the slipstream would miss the tail. The rake surveys provided information which definitely located the slipstream for the various flight conditions. The results are shown in Fig. 10. With

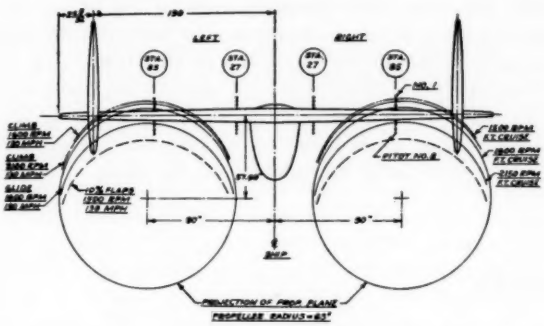

FIG. 10. Slipstream position for various flight conditions; view looking forward.

the wing flaps slightly extended, the slipstream definitely was below the stabilizer. The reduction in vibration as the flaps were extended was so marked that there was no doubt that the vibration was caused by the slipstream hitting the tail.

DESIGN MODIFICATIONS TO REDUCE VIBRATION

The surveys made with the pitot rake eliminated all doubt of the vibration being of aerodynamic origin. Several possible solutions were presented and even though little hope was held for their success they were tried because of their simplicity. Among these were the following:

(1) Static balances were incorporated on the elevator to change its resonance.

(2) The stabilizer was stiffened in vertical bending to change its resonance.

The items above were attempted but when it was clear that the wrong tactics were being employed by trying to suppress the vibration instead of remedying the cause, another attack was made on the problem. This consisted of changing the flow at the wing by the following means:

(3) Expanding fillets were installed at the wing-fuselage junction (as shown in Fig. 11). The pitot rake surveys at the tail had indicated the presence of a turbulent wake near the fuselage. It was thought that this might have been the result of interaction between the slipstream and separation at the wing-fuselage junction. Fig. 12 shows an appreciable reduction in vibration resulted. However, the vibration was still too uncomfortable for airline passenger service.

FIG. 11. Wing-fuselage fillet.

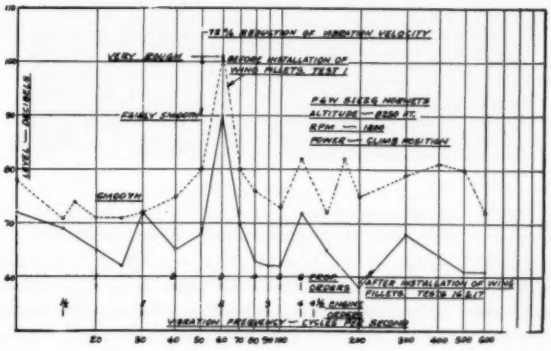

FIG. 12. Effect of wing fillet on amplitude of vibration; experimental Model 1954.

Following the test of the wing fillet, it was concluded that no practical change could be made which would eliminate the source of energy creating the vibration. The answer to the problem seemed to be to change the location of the tail so that the slipstream would not impinge upon it within the normal flight range. This was done by raising the entire tail as a unit, a distance of one foot above its original position. The modification is shown in Fig. 13. The results exceeded expectations; Fig. 14 indicates a 95 per cent reduction in vibration and this was corroborated by "feel."

CONCLUDING REMARKS

This investigation has uncovered some rather unique findings that should influence designers' judgment in

FIG. 13. Raised tail position.

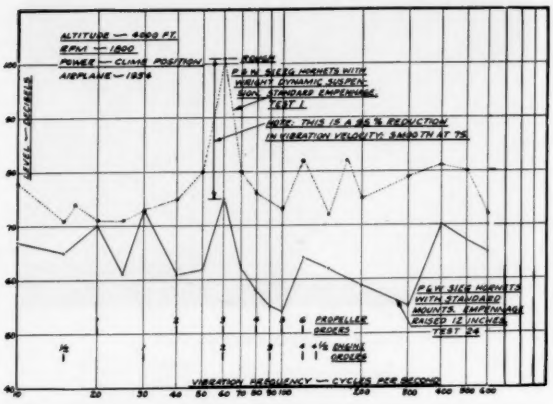

FIG. 14. Effect of raising the tail on the amplitude of vibration.

selecting a tail position. With power wind-tunnel models it would be possible to predict the conditions which were not discovered on the subject model until flight tests were made. Raising the tail did not produce any change in flying characteristics and the effect on performance was very slight. The pitot rake provided the information which yielded the direct solution to the problem. A hot-wire anemometer was also used to study slipstream turbulence but mechanical difficulties with the equipment seriously reduced its value. It showed great promise, however, and undoubtedly will be used in future investigations of this type. Fig. 6 shows the rake which was used to hold the hot-wires. The rake, which protruded through a window in the fuselage, was shock-mounted to prevent fuselage vibration from being transmitted to the wires.

Book Reviews

Simple Aerodynamics, by C. C. CARTER; The Ronald Press Company, New York, 1940 (fifth edition); 510 pages, $4.50.

The fifth edition of *Simple Aerodynamics* is a good elementary approach to aerodynamics from the engineering standpoint. The earlier editions were widely used as textbooks in beginning courses in technical institutes and the revision will probably enjoy a comparable distribution.

While it has not been brought completely up to date in some respects, the basic principles are for the most part adequately explained. No recent data on tapered planforms or on wing-nacelle combinations are included, and tricycle landing gears and multiple tail surfaces are not treated.

Since earlier editions are familiar to aeronautical engineers a detailed description of the contents is unnecessary. Those chapters in the fourth edition on materials and construction, navigation maps and charts, types of military airplanes, and types of aviation engines have been deleted as such. Information on these topics is found in other chapters.

The chapter headings are: "Introduction," including types of aircraft, "The Airfoil," "Criteria for the Selection of Airfoils," "Parasite Resistance," "The Propeller," "The Complete Airplane," "Stability," "The Control Surfaces," "Performance," "Dynamic Loads," and "Aircraft Instruments." Appendices give a description of the autogiro, nomenclature for aeronautics, aerodynamic equations, and problems.

The book has a wealth of illustrations. It is clearly written and in many respects is well adapted to classroom work.

A. M. KUETHE

Properties of Ordinary Water Substance, compiled by N. ERNEST DORSEY; Reinhold Publishing Corporation, New York, 1940; 673 pages, $15.00.

This is another of the American Chemical Society's Series of Scientific and Technologic Monographs, and, in common with other books in the series, is a remarkably complete treatment of its subject. Water in all its phases is treated; physical and chemical data based on literally thousands of references to the technical literature are given.

The part of the book on Ice will be of practical value to those scientists and engineers directly concerned with the solution of aircraft icing problems. Meteorologists will be interested in this section as well as parts of those dealing with synthesis, dissociation, water vapor, water multiple-phase systems, and phase transition. Some curves are given but for the most part, the data are collected in many convenient tables.

An idea of the scope of the book is given by the plan of the committee in charge. It was: (1) to assemble from the *International Critical Tables* all data pertaining to the properties of the ordinary water substance in all its phases; (2) revision and extension of those data in the light of more recent work; and (3) inclusion of types of data omitted from the *Critical Tables.*

Aircraft Maintenance, by DANIEL J. BRIMM, JR., and H. EDWARD BOGGESS; Pitman Publishing Corporation, 1940; 492 pages (lithographed), $2.50.

This book is a revision of a previous work by the same authors, *Airplane and Engine Maintenance.* The material on engines has been removed and the space devoted to a more complete discussion of metal construction.

As a text for the student mechanic, the book should serve well as a handbook or as a basis for home study as it is plentifully supplied with excellent illustrative sketches and photographs of the very latest airplanes and equipment.

The authors deal first with the basic principles of projection, drafting, and blueprint reading, and then progress from woodworking to metal work, fabric work and finishing, and finally rigging, handling, and maintenance. The treatment of these topics is very well handled, basic principles being simply explained and tools and other equipment for various types of work are well described and in most cases illustrated by photographs. The chapter on metal work should be particularly useful to not only student mechanics but to workers in all aircraft plants where production of metal airplanes is being rushed with the greatest possible speed. Both aluminum alloy and stainless steel structures are covered and riveting and welding of all types are carefully explained. A complete list of A–N part numbers is included to enable the student to become familiar with the standard parts available.

It is believed that in addition to its uses as a text and reference book for mechanics and factory workers, the book should prove invaluable to the student or inexperienced aeronautical engineer as a guide to current good practice in the design and construction of aircraft components.

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Boundary Layer and Wake Survey Measurements in Flight and in the Wind Tunnel*

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California Institute of Technology

I. Introduction

DUE to the recent active interest in the effects of boundary layer transition phenomena and surface roughness on drag, an experimental investigation was begun at the GALCIT (Guggenheim Aeronautics Laboratory at the California Institute of Technology) to study these effects in the wind tunnel at Reynolds Numbers from about 3 to 8 million. A large wing of 8.6 ft. span and 5 ft. chord was employed to make this study. The details of the model are discussed in Section II. The wing tests reported here cover only results obtained with a smooth polished wing surface.

Since the beginning of this investigation two aircraft manufacturers have offered airplanes with which to make tests in flight to augment those mentioned above. These airplanes were the Lockheed Model 14 and the Douglas DC-4. The flight test program with these two airplanes was not complete from a research standpoint. However, such tests as were obtained are reported here. The tests were made in a single flight with each airplane and included boundary layer surveys and wake traverses for wing drag determination. The measurements were on the commercial airplanes as manufactured without any wing surface modification whatsoever.

II. Description of Apparatus

The large wing for wind tunnel tests has an 8.6 ft. span and 5 ft. chord. The structure is built up of wood spars and ribs with a 16 gage steel sheet cover. The surface is lacquered and rubbed down to a very high polish (see Fig. 1). The profile of this wing is an N.A.C.A. 0012 section.

The survey of the wake of the wing is carried out by rotating standard Prandtl pitot-static tubes behind the wing. The pitot tubes are at the ends of arms which rotate about an axis parallel to the pitot tubes and perpendicular to the arms themselves. The arms are connected to a hollow shaft which is driven by a small electric motor. The electric motor, an Autosyn unit, the necessary gears, and limit switches are enclosed by a metal box.

FIG. 1. Big wing mounted in the tunnel.

The hollow shaft to which the pitot arms are connected extends through the box and runs on bearings mounted in the box. The Autosyn unit is geared to the shaft and serves to indicate remotely the position of the pitot arms. Limit switches are used to prevent the shaft from turning more than one revolution. Rubber tubes connect the pitot-static tubes to a multiple manometer. These rubber tubes and the electrical cables for the motor and the Autosyn are held together in a cotton sleeving.

In the Douglas DC-4 the box was mounted in the trailing edge of the flap at the outboard end of the flap. The only projection from the wing was the pitot arm which extended through the trailing edge so that the shaft and the pitot-static tubes were parallel to the chord line of the wing (see Fig. 2). The rubber tubes

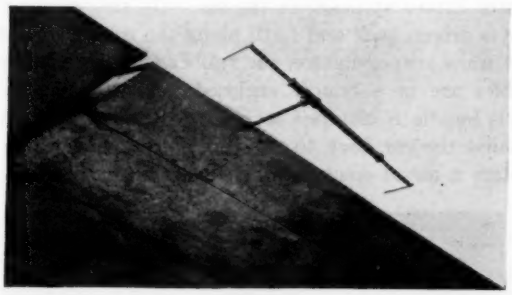

FIG. 2. Wake survey pitot arm on the DC-4.

and cables were carried inside of the wing into the fuselage where they were connected to the instrument panel and controls for the motor. On the Lockheed 14 the box was mounted on a wooden plank behind the wing (see Fig. 3). This plank was supported by the tracks for the Fowler flaps. The bundle of tubes and cables was strung along the trailing edge of the wing

Presented at the Pacific Coast Annual Meeting, I.Ae.S., Pasadena, California, June 15, 16, 17, 1939. Manuscript received March 13, 1940.

* D. L. Putt and C. N. Piper, U. S. Army Air Corps, were responsible for a large part of the initial development work and preliminary tests. Their contributions to this work are contained in unpublished theses on file at the GALCIT.

FIG. 3. Wake survey pitot arm and boundary layer exploring mechanism on the Lockheed 14.

and through a window into the cabin. The external mounting was used because there was not sufficient room in the wing to hold the box. In the wind tunnel the box was mounted on a wooden plank which extended across the tunnel behind the wing (see Fig. 4).

The boundary layer measurements are made by moving small total head tubes fore and aft along the wing at small fixed distances from the surface of the wing. The small total head tubes are mounted on a frame connected to an arm extending to one side from a car which holds a small electric motor and an Autosyn

FIG. 4. Wake survey box mounted in the wind tunnel.

unit (see Fig. 5). The car runs on a track made of two extruded bulb angles which are bent to fit the contour of the wing. A chain, which is fastened at each end of the track, runs down the middle of the track and over a motor driven sprocket in the car. By this means the car is driven back and forth along the track. As with the wake survey device, the rubber tubes and electric cables are in a bundle enclosed by cotton sleeving. This bundle is clamped securely to the car and trails behind the car back to the rear of the wing where it enters a metal conduit which leads into the cabin of the airplane. The Autosyn unit indicates the position of the car on the track. There are limit switches which prevent the car from running off the end of the track. The arm extending from the car is long enough to put the total head tubes outside of any disturbance caused by the track and car. The tubes are constructed of hypodermic needle tubing which is flattened at the end to give a nearly rectangular hole. The tubes are mounted so that as they move along the wing they maintain the same distances from the surface. Fig. 6 shows the dimensions of the total head tubes and their spacing from the wing surface. This tube setup was used on both the DC-4 and Lockheed 14 tests.

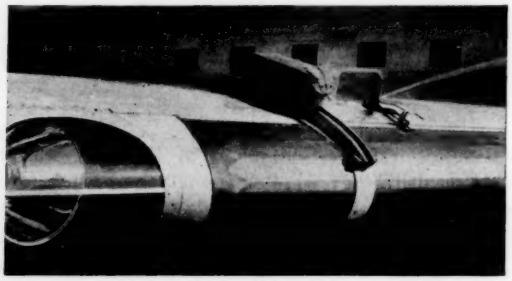

FIG. 5. Boundary layer exploring mechanism on the DC-4.

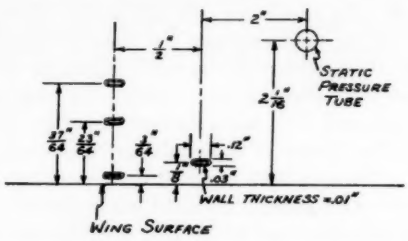

FIG. 6. Front view sketch of the boundary layer survey tubes.

The same piece of track was used on the DC-4 and on the Lockheed 14. A short straight piece of track was used on the large wing in the wind tunnel. There is sufficient flexibility in the mounting of the arm so that it is not necessary for the track to fit the contour of the wing with any great accuracy. Fig. 7 shows the location of the wake survey and boundary layer traverse planes on the DC-4 and Lockheed 14 wings.

The instrument panel (see Fig. 8) at which all readings are taken contains a multiple manometer, two Autosyn indicators, an altimeter, an air speed indicator,

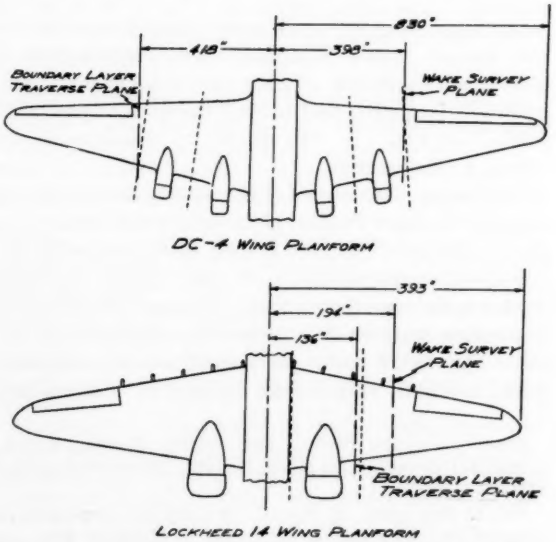

FIG. 7. Location of the wake survey and boundary layer traverse planes.

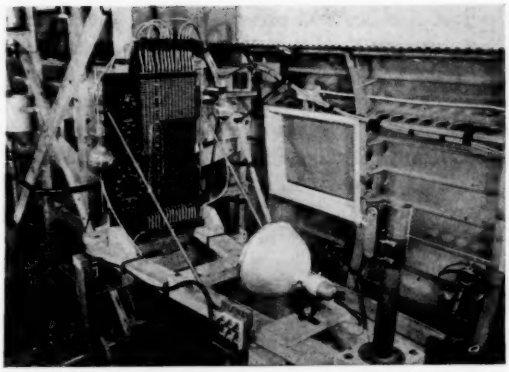

FIG. 8. Instrument panel installed in the DC-4 cabin.

and a counter for identification purposes. The instrument panel is photographed by a miniature camera. In this way readings are obtained simultaneously and quickly. The panel holds instruments for both the wake survey and the boundary layer measurements. The motors which drive the apparatus are controlled by switches near the instrument panel. Pictures are taken as quickly as the positions of the measuring tubes can be changed.

III. Method of Reducing Data and Presenting Results

Pitot Traverses

The profile drag of a wing may be determined by measurement of the momentum deficiency of the airstream in the wake behind the wing.

A suitable and practical method of converting total head and static pressure measurements from a pitot traverse across the wake to drag coefficient has been developed by B. M. Jones.[1]

The working formula is

$$C_{D_P} = 2\int \sqrt{g - p}(1 - \sqrt{g})\, d\,(y/t) \qquad (1)$$

where

C_{D_P} = profile drag coefficient
g = H/H_0
p = P/H_0
y = vertical coordinate in a traverse across the wake
t = chord of wing at measuring plane
H = total head at any point in the wake
P = static pressure at any point in the wake
H_0 = free stream total head measured by airplane pitot-static tube.

All pressures are referred to the free stream static pressure. Fig. 9 serves to define more clearly the above quantities.

The C_{D_P} as given in Eq. (1) represents the section drag of the wing section in front of the measuring plane. The measuring plane is considered as that in which the pitot tube lies when at the center of the wake. The spanwise motion of the tube in swinging in its arc of 18 inch radius is only about 0.4 inch maximum. Any small correction due to this spanwise motion is neglected. In order to obtain the overall wing drag in the wind tunnel, measurements were made at a number of spanwise stations. The flight tests reported here are at only one station for each airplane.

For the tests on both the DC-4 and the Lockheed 14 all pressure readings were referred to the free stream static pressure by connecting a line to the static pressure side of the airplane pitot-static tube. All the results have been corrected for fuselage interference on the pitot tube from airspeed calibration data furnished by the respective companies.

At the beginning of the tests on the DC-4, it was discovered that the pitot traverse tubes were located in the edge of the outboard propeller slipstream. In order to calculate the correct value of drag coefficient, the following analysis was employed to find the amount of correction to be applied to the results to account for this slipstream effect:

The Jones equation is satisfied only when the total head outside the wing wake is the same as that in front of the wing (see Fig. 9). In the normal case this total head may be determined from the airplane pitot tube, but in this special case it was assumed that the "free stream" total head was that recorded outside the wake but in the propeller slipstream. This assumption introduced a further difficulty inasmuch as this "free stream" total head outside the wake was not the same on the two sides of the wing. In the actual computations a preliminary curve of H/H_0 *vs.* y/t may be plotted, resulting in a curve as shown in Fig. 10.

If the difference between the dotted lines of Fig. 10 is denoted by ΔH then the drag coefficient as expressed by Eq. (1) becomes

$$C_{D_P} = 2\int \sqrt{g_c - p_c}\,(1 - \sqrt{g_c})\, d\,(y/t) \qquad (2)$$

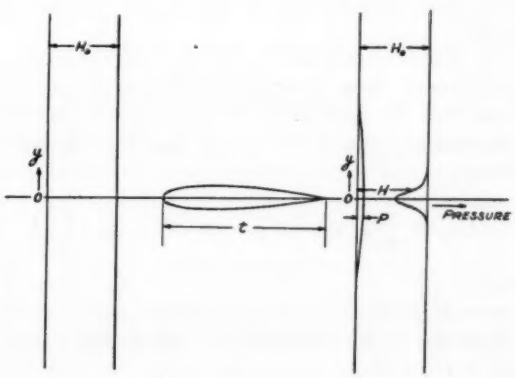

FIG. 9.

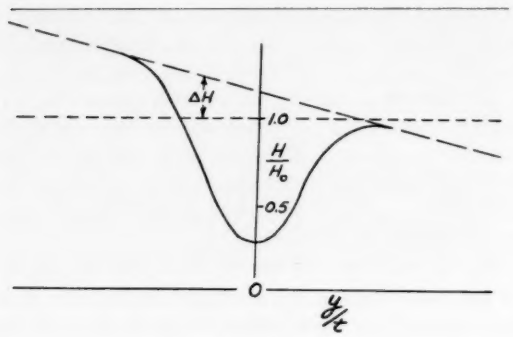

FIG. 10.

where

$$g_c = \frac{H}{H_0 + \Delta H}, \quad p_c = \frac{P}{H_0 + \Delta H}$$

or

$$g_c = g\left(\frac{1}{1 + \Delta g}\right), \; p_c = p\left(\frac{1}{1 + \Delta g}\right), \quad \Delta g = \frac{\Delta H}{H_0}$$

or writing Eq. (2) so that the slipstream correction factor appears explicitly,

$$C_{D_P} = 2\int \sqrt{\frac{1}{1 + \Delta g}}\left(\sqrt{g - p}\right) \times \left(1 - \sqrt{g}\sqrt{\frac{1}{1 + \Delta g}}\right) d\left(\frac{y}{t}\right) \quad (3)$$

The correction term $\sqrt{1/(1 + \Delta g)}$ is a function of y/t. This function varies for each speed since the propeller thrust varies with speed, and its value was determined for each run from a preliminary plot of H/H_0 *vs.* y/t.

During the DC-4 tests a check run was made with the outboard port propeller feathered in order to get an experimental estimate of this slipstream effect, but, unfortunately, for some undetermined reason the results of this check run are not consistent and hence not to be trusted as a check on the above assumptions to account for the slipstream effect.

In the case of the Lockheed 14 tests no such complication of slipstream interference arose inasmuch as the survey plane was located outside of the propeller slipstream.

The Jones formula of Eq. (1) may also be employed to determine drags from wake surveys in the wind tunnel, but the application requires some explanation.

Referring to Fig. 11 it is clear that Eq. (1) may be written

$$C_{D_P} = \frac{2}{q_0}\int \sqrt{q}\,[\sqrt{q_0} - \sqrt{H - P_0}]\, d\left(\frac{y}{t}\right) \quad (4)$$

where

$q = H_1 - P_1$
$q_0 = H_{1F} - K - P_0 = H_{1F} - (K + P_0)$
$H = H_1 - K$
$H - P_0 = H_1 - (K + P_0)$

Subscript F indicates a pressure outside the wake.

Now suppose $K + P_0 = P_{1F}$ where P_{1F} is static pressure above piezometer ring pressure outside the influence of the wing. It should be pointed out that this pressure may not be reached except at a considerable distance from the wake. Hence it is sometimes difficult to measure directly.

Then

$$q_0 = H_{1F} - P_{1F} = a\,q_T$$

where

q_T = wind tunnel dynamic pressure at the centerline of tunnel
a = ratio of tunnel dynamic pressure at any spanwise position to that at the centerline.

Eq. (4) may be written

$$C_{D_P} = \frac{2}{H_{1F} - P_{1F}}\int \sqrt{H_1 - P_1} \times [\sqrt{H_{1F} - P_{1F}} - \sqrt{H_1 - P_{1F}}]\, d\left(\frac{y}{t}\right) \quad (5)$$

Here all quantities may be easily measured in the tunnel except P_{1F}.

The wind tunnel speed is set to give the proper average q across the span of the wing. Hence at the centerline of the tunnel the actual q is higher than that indicated by the tunnel manometer setting. Assume that the value of P_{1F} is constant across the wing span and its value is determined by

$$P_{1F} = [H_{1F} - q_T]_{\text{centerline}}$$

$q_T = q_0$ at centerline and comes from wind tunnel calibration with no model in the tunnel. The above assumption is valid when there is no curvature of the flow through the tunnel working section.

Then a is obtained for any spanwise position of traverse by

$$a = (H_{1F} - P_{1F})/q_T$$

Writing $g_1 = H_1/q_T$ and $p_1 = P_1/q_T$, the final working formula for drag, which is applicable in the wind tunnel, is

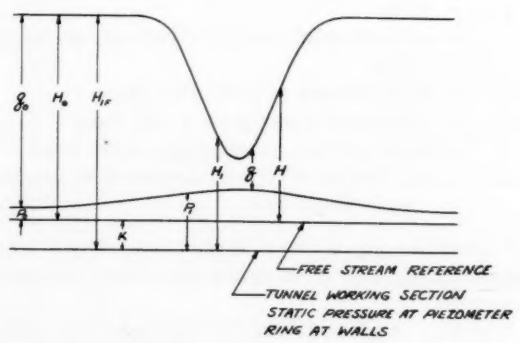

FIG. 11.

$$C_{D_P} = \frac{2}{\sqrt{a}} \int \sqrt{g_1 - p_1} \left[1 - \frac{1}{\sqrt{a}} \sqrt{g_1 - p_{1F}} \right] d\left(\frac{y}{t}\right) \tag{6}$$

(For the GALCIT 10 ft. tunnel $p_{1F} = P_{1F}/q_T = 0.009$.)

Boundary Layer Surveys

The technique employed in exploring the boundary layer to study transition phenomena in flight was essentially that developed by B. M. Jones.[2] The details of the apparatus are somewhat different from his as is noted in the description of the testing equipment.

This apparatus lends itself to the measurement of two quantities pertaining to the boundary layer over the surface of a wing. Firstly, with four total head tubes spaced at different distances from the wing surface and an accompanying static pressure tube, readings of pressure are obtained which enable the plotting of a crude velocity profile of the flow in the boundary layer. However, since only 4 points on the profile are measured, a very reliable profile cannot be obtained. Secondly, and more important, the total head tube measurements afford a means of determining the location, in a chordwise direction, of the transition from a laminar to a turbulent boundary layer.

Laminar and turbulent boundary layers are identified by the following distinguishing characteristics of their velocity profiles (see Fig. 12). If a total head

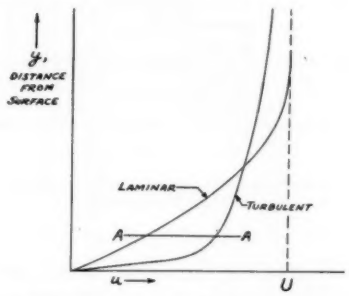

FIG. 12. Typical laminar and turbulent boundary layer velocity profiles.

tube is traversed in a chordwise direction, the tube maintaining a small constant distance from the wing surface, the total pressure will decrease as the distance from the stagnation point is increased until the transition is approached. If the tube is at a distance from the surface denoted by section *A-A* of Fig. 12 the tube will record rising total pressure as the transition is reached and then gradually falling pressure as the chordwise traverse is continued further. A characteristic rise or hump in a total head distribution curve in a chordwise direction, therefore, indicates the existence of a transition point in the vicinity of its occurrence. This, of course, applies only to the tubes nearest the wing surface.

Due to the fact that 4 total head tubes were used, another method of locating transition may be employed. If all tubes are initially outside the boundary layer near the stagnation point, then, as the rearward chordwise traverse proceeds, each tube will at some point begin to record dropping pressures. This drop indicates the entrance of a tube into the boundary layer. Knowing the tube spacing normal to the wing surface and the position at which each tube begins to experience a drop in pressure, a plot of the boundary layer thickness as a function of the chordwise position is obtained. If this is done only for the tubes which are sufficiently far from the surface so as not to enter the boundary layer until it has become turbulent, this layer thickness will be that for a turbulent boundary layer. If the thickness of the laminar boundary layer is calculated using the measured static pressure gradient over the wing surface and making some reasonable assumption as to an appropriate laminar velocity profile, then the intersection of this curve with that determined experimentally for the turbulent layer thickness indicates the transition region.

For both the DC-4 and Lockheed 14 tests the transition points were determined by both these methods and are discussed in Section IV.

The non-dimensional quantities employed to plot the boundary layer survey results are defined as follows:

$$g = H/H_0; \quad \lambda = x/t$$

where

- H = total head measured by any tube in the boundary layer relative to free stream static pressure
- H_0 = free stream total head relative to free stream static pressure (measured by airplane pitot tube)
- x = distance along the surface in a chordwise direction downstream from the wing leading edge at the measuring station (in wind tunnel x is measured parallel to chord)
- t = chord of wing at measuring station
- n = distance to the center of any total head tube from the wing surface measured normal to the surface (subscript denotes the particular tube in question)
- δ = boundary layer thickness.

The technique of reducing the data and presenting results in the case of boundary layer surveys made in the wind tunnel is the same as that discussed above.

IV. Discussion of Results

In Fig. 13 are collected some results of drag measurements in various wind tunnels and in flight. An examination of these curves reveals the need for some real understanding of the various factors influencing drag

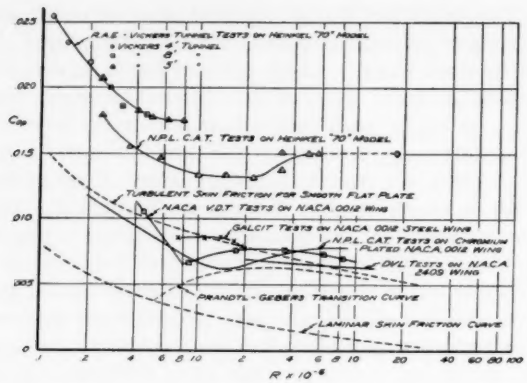
R.A.E. - VICKERS TUNNEL TESTS ON HEINKEL "70" MODEL
VICKERS 4' TUNNEL
N.P.L. C.A.T. TESTS ON HEINKEL "70" MODEL
TURBULENT SKIN FRICTION FOR SMOOTH FLAT PLATE
N.A.C.A. V.D.T. TESTS ON N.A.C.A. 0012 WING
GALCIT TESTS ON N.A.C.A. 0012 STEEL WING
N.P.L. CAT TESTS ON CHROMIUM PLATED N.A.C.A. 0012 WING
DVL TESTS ON N.A.C.A. 2409 WING
PRANDTL - GEBERS TRANSITION CURVE
LAMINAR SKIN FRICTION CURVE
C_{dp}
$R \times 10^{-6}$

FIG. 13. A collection of drag measurements.

as a function of Reynolds Number in order to explain the wide variation in character of the curves presented in this figure. The two important quantities believed to influence these curves most are the location of the transition point or region on the wing where the boundary layer changes from a laminar to a turbulent one, and the local roughness on the wing surface.

Wind Tunnel Results

The present report on the wind tunnel results is concerned only with the first item since the wing has not yet been tested with roughness of varying degrees on the surface.

Fig. 14 shows a typical set of results of total head measurements over the upper surface of the 5 ft. chord N.A.C.A. 0012 wing section. This set of curves demonstrates the amount of experimental scatter, which is rather small. The curves are selected from a group of tests made, after several trials, to obtain some semblance of consistent data. It is to be noted that the transition points as defined above are indicated in Fig. 14. These curves indicate what a wide transition region is obtained from the surface tube readings, and that to speak of a transition point requires some arbitrary definition of it. This arbitrary point is defined as the point of tangency of a horizontal line with the plots of total head ratio *vs.* x/t (or minimum pressure point) (see Fig. 14). Also from the point of entry of each total head tube into the boundary layer, as indicated by the drop in pressure, the boundary layer thickness curves are drawn. The beginning of the transition region as given by the boundary layer thickness curves is consistent with that obtained from the surface tube readings (see Fig. 14, $\alpha_u = 0°$).

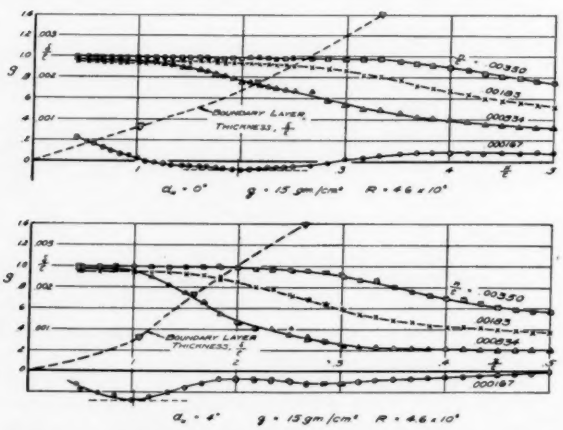

FIG. 14. Boundary layer total head measurements on upper surface GALCIT big wing.

The fact that the total head ratio, g, for the surface tube goes below zero is of no consequence. This occurs because the reference static pressure was that of the free stream and not the local static pressure outside the wake in the vicinity of the point in question. Pressure distributions over the explored sections are not included in this paper but the experimental curves are on file at the GALCIT.

Measurements of the total heads were made for a series of angles of attack from 0° to 10°, and the results of these measurements appear in Fig. 15. No curves for angles of attack greater than 6° are given, for the reason that for these angles the transition point was ahead of the forward measuring station. The dashed radial lines correspond to constant chordwise positions of transition. From these it appears that as the Reynolds Number is increased the transition point moves forward to some limiting value as indicated by tangency to a radial line. This limiting point may possibly be the minimum pressure point. As the Reynolds Number, R, decreases, the curves indicate that the transition Reynolds Number, R_x, reaches a constant value, which varies with the angle of attack or pressure gradient over the wing.

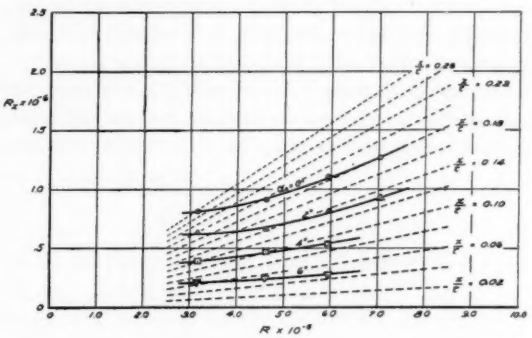

FIG. 15. Transition position measurements on upper surface GALCIT big wing.

Fig. 16 shows some results plotted in the same form but taken from some N.A.C.A. Full Scale Tunnel measurements.[3] A comparison of Figs. 15 and 16 shows that the variation of R_x with angle of attack is roughly the same, but that the variation with R is quite different.

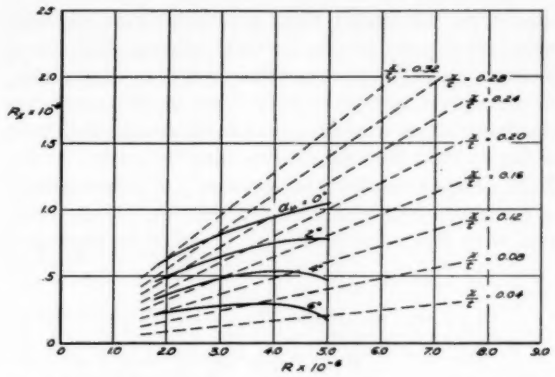

FIG. 16. Transition position measurements on upper surface of 0012 airfoil from reference 3.

Fig. 17 shows the results of a complete spanwise drag survey by the momentum method on the 5 ft. chord wind tunnel model. The drag distribution appears to be fairly constant over the span except at the tips. This tip effect is not new and has been reported in some of the N.A.C.A. investigations.[4] It is to be noted that the drag falls to zero before the extreme tip is reached so the hump is probably due to the concentration of drag inboard which comes from the three-dimensional surface of the rounded tip. Considering the dotted line

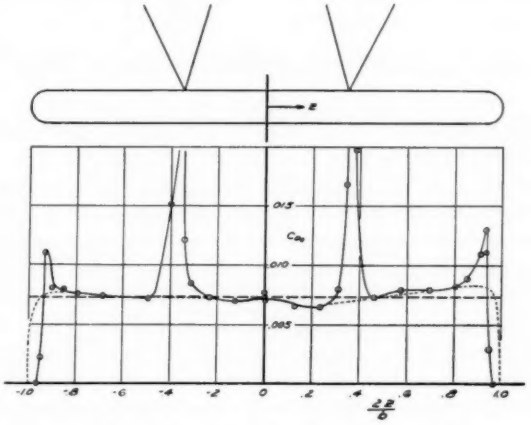

FIG. 17. Spanwise drag survey on big wing. Angle of attack 0°, $R = 5.94 \times 10^6$.

which is faired smoothly out to a value of $2Z/b = 1$, the same mean drag is obtained as is given by taking the solid curve with the hump. The high drag peaks near the center are due to the wire supporting system in the tunnel. These were ignored in determining the mean drag value for the wing. This mean value at zero lift and a Reynolds Number of 5.94×10^6 is $C_{D_0} = 0.0073$.

Fig. 18 compares the wing drag as obtained by balance readings and wake surveys. The lift coefficients used to plot the wake survey curve are section lift coefficients for the measured geometric angle of attack. These section lift coefficients are taken from Fig. 10 of reference 4. The drag curve from balance readings is not plotted for large values of C_L since the wing aspect ratio is low and the induced drag effects are large. The discrepancy between balance measurements and wake surveys may possibly be due to inaccuracies in the tare drags for this large chord wing. There is no Reynolds Number variation of drag for either case. This is discussed again in connection with Fig. 19.

Fig. 19 shows a correlation between the drag survey measurements and boundary layer transition measurements. The curves of profile drag *vs.* Reynolds Number for various transition points are taken from reference 5. The dashed curve corresponds to the profile drag curve which is obtained by interpolating for the various transition points as measured on the big wing. The solid straight line represents the wake survey measurements of drag. The comparison here explains the failure to obtain any variation of drag with Reynolds Number. It appears that the forward movement of the transition

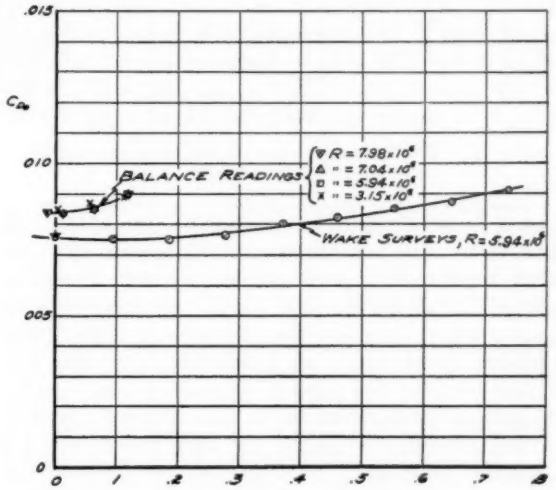

FIG. 18. Profile drag of GALCIT big wing. The abscissa is C_L.

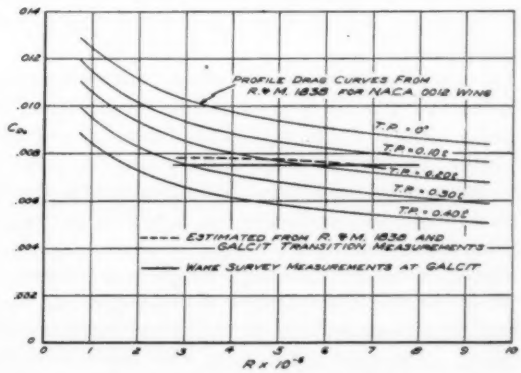

FIG. 19. Measured and estimated profile drag coefficients *vs.* Reynolds Number for 0° angle of attack.

point with Reynolds Number just about compensates for the normal reduction in drag with Reynolds Number for a fixed transition point.

Flight Tests Results

Since neither sufficient time nor facilities were available for preliminary experimentation in flight, the boundary layer survey results are not very fruitful. A sample set of these surveys is shown in Fig. 20. These

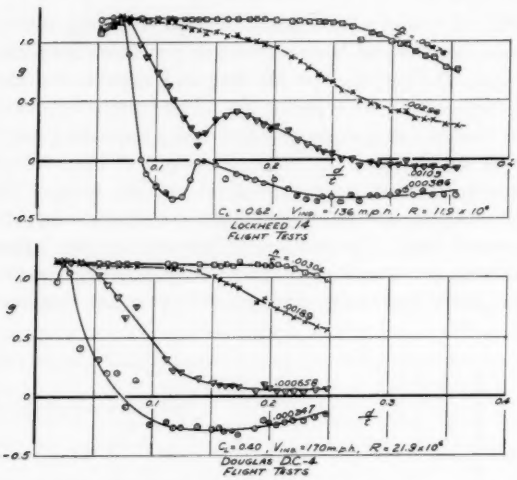

FIG. 20. Boundary layer total head measurements in flight, upper surface.

curves must be used with considerable care as to interpretation. The boundary layer thicknesses indicated that no transition took place over the measuring region. Although the curve for the Lockheed 14 tests indicates that there may be a transition at about the 12 per cent chord point, this is believed to be some disturbance in the flow caused by rivets, joints, or some roughness. Unfortunately for both sets of flight tests it was necessary to mount the surveying tubes in a propeller slipstream. It is felt that the slipstream is sufficient to produce a turbulent boundary layer at or very near the stagnation point. Hence these curves only indicate the character of the boundary layer in the slipstream and on wings of ordinary commercial manufacture.

The wake survey measurements are somewhat more satisfactory. Fig. 21 shows a sample set of curves obtained. These are plots of the drag function developed by Jones, the area under the curve giving the value of drag for a given condition. The experimental scatter is small, which makes this method of measuring drag in flight rather promising.

Fig. 22 compares the wing drags as measured in flight on the two airplanes with the corresponding wind tunnel drag measurements on the model wings of each airplane. The wind tunnel data were taken from the GALCIT 10 ft. tunnel results. The extremely small scatter in the flight test points is encouraging. It should be mentioned that the flight measurements were made only at one section, whereas the tunnel measurements are mean values for the whole wing. Fortunately the section thicknesses at the measuring stations in flight were very close to the mean wing thicknesses so that the comparisons may be made. In the flight results two effects are present: (1) the variation of the profile drag with lift coefficient, and (2) the variation with Reynolds Number. In order to attempt a

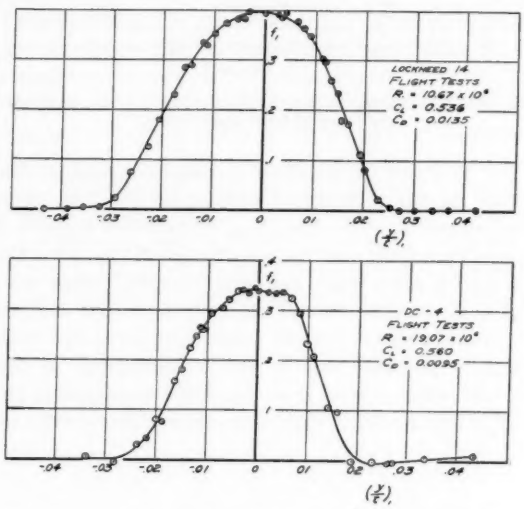

FIG. 21. The Jones drag function as measured in flight.

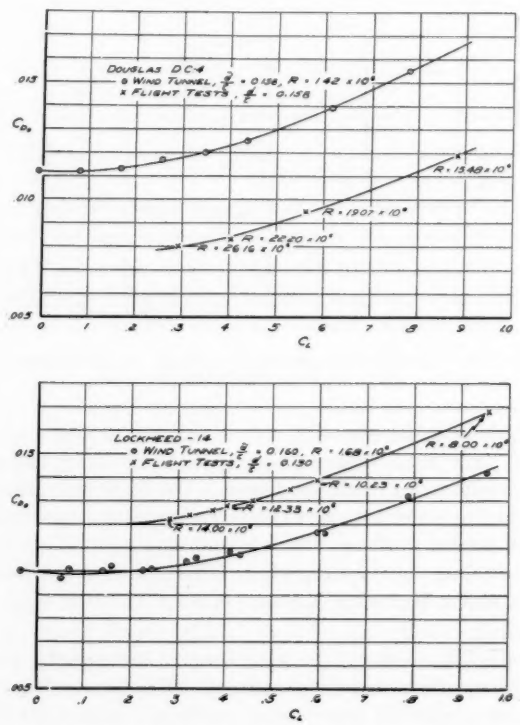

FIG. 22. C_{D_0} *vs.* C_L from wind tunnel and flight.

separation of these effects Fig. 23 is plotted. The indicated extrapolations are made by assuming that the variation of profile drag with Reynolds Number follows von Kármán's skin friction law for smooth flat plates with turbulent boundary layers.[6] This is done by

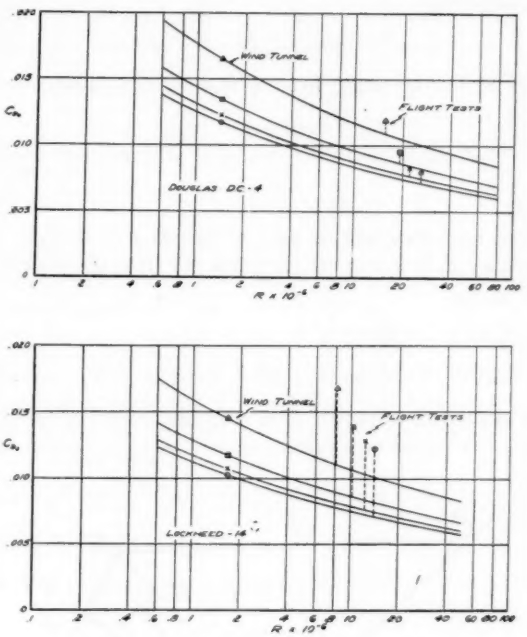

FIG. 23. Scale and roughness effect on two airplane wings.

assuming that the drag coefficient at a definite Reynolds Number is given by the ratio of drag coefficient measured at a given Reynolds Number to the skin friction coefficient at that Reynolds Number multiplied by the skin friction coefficient at the chosen Reynolds Number. The curves are adjusted to pass through the wind tunnel model test points, these points being chosen at the same lift coefficients as the flight test points. The failure of the flight test points to fall on their respective curves is probably attributable to surface roughness on the full scale wings. For the DC-4 wing which is flush riveted but has some roughness around the deicer the roughness increment is about $\Delta C_{D_P} = 0.0009$. For the Lockheed 14 wing with normal Brazier head rivets the roughness increment is about $\Delta C_{D_P} = 0.0052$.

CONCLUSIONS

The results of this investigation show that the apparatus developed for measuring wing section drags in flight is practical and is amenable to quick adaptation to a full scale airplane. The boundary layer surveying equipment was successful as far as its mechanical operation was concerned but caution should always be taken to keep the surveying plane outside the propeller slipstream. A technique has been developed so that rapid measurements can be made in order to reduce the expense of flight testing. The real value of the tests will be enhanced when additional measurements may be made with smoother surfaces in flight and rougher surfaces in the wind tunnel.

The wind tunnel measurements furnish further evidence to corroborate contentions in other papers that transition does not occur at a particular transition Reynolds Number, R_x. The correlation between transition and drag measurements in the wind tunnel is excellent. The detrimental effect of rivets on drag is very evident from the flight wake survey results.

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Book Review

The Air and Its Mysteries, by C. M. BOTLEY, American edition arranged by HANOR A. WEBB; D. Appleton-Century Company, New York, 1940; 302 pages, $3.00.

The foreword, written by Sir Richard Gregory, states that this book falls into the category of those that "record the methods and results of observation and experiment by which natural knowledge is advanced and principles established for the practical service and intellectual expansion of mankind." Written primarily for the general reader it is a lucid and well-illustrated account of the weather and its vagaries. The original edition, written in England, was adapted for North American readers by Hanor A. Webb. The result is particularly pleasing.

Beginning with a discussion of air, its functions and constituents, the reader is led through interesting explanations of clouds and their types, rain, thunderstorms, weather in general, climate, light and sound transmission in the air, flight and stratosphere investigations.

The chapter on flight includes interesting descriptions of man's flight in balloons, airships, and airplanes, as well as the flight of birds, beasts, and insects.

Approximate Formulas for Piston Travel in Radial Engines

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ABSTRACT

A simplified equation involving two Fourier series is given for the piston travel when the angular spacing of knuckle pin holes equals the angular spacing of the cylinder axes. Tables are given for determining the coefficients and phase angles of these two Fourier series. Formulas and tables are also given for finding the error due to using only the first two terms of these series. A simplified approximate formula for piston travel is also given, from which formulas for maximum and minimum piston travel are derived.

INTRODUCTION

THE motion of the master cylinder piston is relatively simple since the crank end of the master connecting rod moves in a circle. However, the motion of each of the other pistons is very complicated because the crank end of its connecting rod (articulated rod) is not connected directly to the crank pin but is fastened by a knuckle pin to the master connecting rod.

No usable formula has yet been given for the most general case of a piston with an articulated connecting rod, but formulas have been found by Root[1] and by Bentley and Taylor[2] for the case in which the angle α between the master rod axis and the line connecting the centers of the knuckle and crank pins is equal to the angle β between the axis of the cylinder in question and the master cylinder axis (Fig. 1). Root expresses the piston travel as a Fourier series of the crank angle with each coefficient itself a Fourier series of the angle β; a solution in this form is quite cumbersome. Bentley and Taylor give an approximate formula for the special case in which the sum of the length of the articulated rod and the distance between centers of crank and knuckle pins is equal to the master rod length, or $l + r = L$ (Fig. 1). In this article, a relatively simple formula will be developed for the special case of $\alpha = \beta$, but without the restriction that $l + r = L$.

GENERAL CASE

Fig. 1 shows the linkage for the master cylinder and one of the other cylinders of a radial engine. Point O is the center of the crank shaft; P and P' are the centers of the wrist pins of the master and other cylinder, respectively; C and C' are the centers of the crank and knuckle pins, respectively. Lines CG and CF are parallel, respectively, to OP and OP'; while $C'E$ and CD are both perpendicular to OP'. Let $OP' = S'$. Let ϕ' be the angle from $P'O$ to $P'C'$. Then, from Fig. 1,

$$S' = R\cos(\theta - \beta) + r\cos(\alpha - \beta - \phi) + l\cos\phi' \tag{1}$$

This formula could be used to calculate S' because ϕ' and ϕ can be found for any value of θ from the relations (Fig. 1)

$$L\sin\phi = R\sin\theta \tag{2}$$

$$l\sin\phi' = R\sin(\theta - \beta) + r\sin(\alpha - \beta - \phi) \tag{3}$$

However, it would be very difficult to find either the velocity or the acceleration from Eqs. (1), (2), and (3).

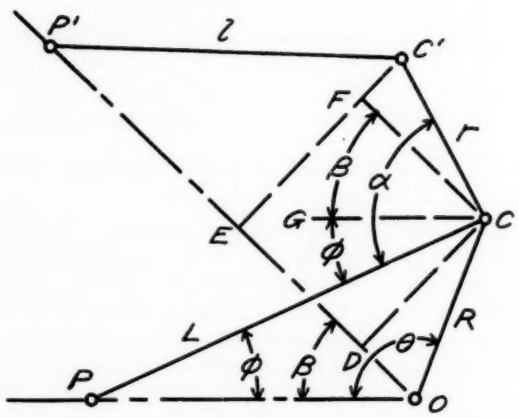

FIG. 1.

SPECIAL CASE OF $\alpha = \beta$

In practically all modern radial engines $\alpha = \beta$. For this special case Eqs. (1) and (3) become, respectively,

$$S' = R\cos(\theta - \beta) + r\cos\phi + l\cos\phi' \tag{4}$$

$$l\sin\phi' = R\sin(\theta - \beta) - r\sin\phi \tag{5}$$

It will be convenient to introduce two quantities c and δ defined by the relations

$$c^2 = \sin^2\beta + (\cos\beta - r/L)^2 = 1 + (r/L)^2 - 2(r/L)\cos\beta \tag{6}$$

$$\sin\beta = c\sin\delta,\ \cos\beta - r/L = c\cos\delta \tag{7}$$

By means of Eqs. (2) and (7) and the relation $\sin(\theta - \beta) = \sin\theta\cos\beta - \cos\theta\sin\beta$, Eq. (5) becomes

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$$l \sin \phi' = Rc(\sin \theta \cos \delta - \cos \theta \sin \delta) = Rc \sin (\theta - \delta) \quad (8)$$

By virtue of Eq. (7)

$$\cot \delta = \cot \beta - (r/L)csc\ \beta \quad (9)$$

Eq. (9) is the simplest relation for calculating δ. Finally, from Eqs. (2) and (8), respectively,

$$\sin \phi = p \sin \theta \quad (10)$$

$$\sin \phi' = p' \sin (\theta - \delta) \quad (11)$$

in which

$$p = R/L;\ p' = Rc/l \quad (12)$$

For the convenience of the designer values of c and δ are given in Tables 2, 3, 4, and 5 for 5-, 7-, and 9-cylinder radial engines.

Tanaka[3] has shown how $\cos \phi = \sqrt{(1 - \sin^2 \phi)} = \sqrt{(1 - p^2 \sin^2 \theta)}$ can be expanded by the Binomial Theorem in powers of $\sin \theta$ and then each even power of $\sin \theta$ expressed in terms of $\cos 2\theta$, $\cos 4\theta$, $\cos 6\theta$, ... The final result is

$$\cos \phi = 1 + p(-b_0 + b_2 \cos 2\theta - b_4 \cos 4\theta + \ldots) \quad (13)$$

in which

$$b_0 = p/4 + 3p^3/64 + 5p^5/256 + 175p^7/16{,}384 + \ldots \quad (14)$$

$$b_2 = p/4 + p^3/16 + 15p^5/512 + 35p^7/2048 + \ldots \quad (15)$$

$$b_4 = p^3/64 + 3p^5/256 + 35p^7/4096 + \ldots \quad (16)$$

Note that the constants a_0, a_2, and a_4 usually given for the master cylinder[2] have the values: $a_0 = 1 + b_0$, $a_2 = -b_2$, $a_4 = b_4$. Values of b_0 and b_2 are listed in Table 1.

A comparison of Eq. (11) with Eq. (10) shows that ϕ' is the same function of p' and $(\theta - \delta)$ as ϕ is of p and θ. Hence by analogy to Eq. (13)

$$\cos \phi' = 1 + p'[-b_0' + b_2' \cos 2(\theta - \delta) - b_4' \cos 4(\theta - \delta) + \ldots] \quad (17)$$

TABLE 1

Coefficients and Errors

p or p'	b_0 or b_0'	b_2 or b_2'	e_2 or e_2'	E_2 or E_2'
0.20	0.05038	0.05051	0.00013	0.00209
0.22	0.05551	0.05568	0.00017	0.00280
0.24	0.06066	0.06089	0.00023	0.00367
0.26	0.06585	0.06614	0.00029	0.00472
0.28	0.07106	0.07143	0.00037	0.00597
0.30	0.07632	0.07676	0.00046	0.00743
0.32	0.08161	0.08215	0.00056	0.00915
0.34	0.08694	0.08760	0.00068	0.01114
0.36	0.09231	0.09311	0.00082	0.01344
0.38	0.09774	0.09868	0.00098	0.01609
0.40	0.10322	0.10433	0.00116	0.01911

in which each primed b is the same function of p' as the corresponding b is of p.

It will be convenient to let

$$q = [(r + l)/R] - (b_0 r/L) - b_0' c \quad (18)$$

Then from Eqs. (4), (12), (13), and (17)

$$S'/R = q + \cos (\theta - \beta) + (r/L)(b_2 \cos 2\theta - b_4 \cos 4\theta + \ldots) + c[b_2' \cos 2(\theta - \delta) - b_4' \cos 4(\theta - \delta) + \ldots] \quad (19)$$

TABLE 2

c for 5- and 7-Cylinder Engines

	5-Cylinder		7-Cylinder		
R'/L	$\beta = \pm 72°$	$\beta = \pm 144°$	$\beta = \pm 51\frac{3}{7}°$	$\beta = \pm 102\frac{6}{7}°$	$\beta = \pm 154\frac{3}{7}°$
0.15	0.96426	1.12481	0.91403	1.04367	1.13701
0.17	0.96116	1.14191	0.90383	1.05098	1.15552
0.19	0.95847	1.15911	0.89397	1.05861	1.17408
0.21	0.95620	1.17639	0.88444	1.06656	1.19269
0.23	0.95433	1.19375	0.87527	1.07483	1.21134
0.25	0.95289	1.21120	0.86646	1.08340	1.23003

TABLE 3

2δ for 5- and 7-Cylinder Engines

	5-Cylinder		7-Cylinder		
r/L	$\beta = 72°$	$\beta = 144°$	$\beta = 51\frac{3}{7}°$	$\beta = 102\frac{6}{7}°$	$\beta = 154\frac{3}{7}°$
0.15	161° 1′	296° 59′	117° 36′	221° 49′	315° 8′
0.17	163° 22′	298° 2′	119° 46′	223° 52′	315° 53′
0.19	165° 44′	299° 4′	121° 59′	225° 52′	316° 37′
0.21	168° 7′	300° 3′	124° 15′	227° 51′	317° 20′
0.23	170° 30′	301° 0′	126° 34′	229° 48′	318° 1′
0.25	172° 54′	301° 56′	128° 56′	231° 43′	318° 41′

NOTE: 2δ is negative when β is negative.

TABLE 4

c for 9-Cylinder Engines

R'/L	$\beta = \pm 40°$	$\beta = \pm 80°$	$\beta = \pm 120°$	$\beta = \pm 160°$
0.15	0.89033	0.98509	1.08282	1.14211
0.17	0.87661	0.98481	1.09494	1.16120
0.19	0.86314	0.98494	1.10729	1.18033
0.21	0.84992	0.98548	1.11987	1.19949
0.23	0.83697	0.98642	1.13265	1.21867
0.25	0.82431	0.98776	1.14564	1.23788

NOTE: The minimum for $\pm 80°$ is $\sin 80° = 0.98481$, corresponding to $R'/L = \cos 80° = 0.17365$.

TABLE 5

2δ for 9-Cylinder Engines

r/L	$\beta = 40°$	$\beta = 80°$	$\beta = 120°$	$\beta = 160°$
0.15	92° 26′	177° 15′	253° 47′	325° 9′
0.17	94° 19′	179° 34′	255° 27′	325° 44′
0.19	96° 16′	181° 54′	257° 6′	326° 19′
0.21	98° 17′	184° 14′	258° 42′	326° 52′
0.23	100° 21′	186° 33′	260° 15′	327° 24′
0.25	102° 29′	188° 52′	261° 47′	327° 55′

NOTE: 2δ is negative when β is negative.

Let V_C and a_C be, respectively, the tangential speed and the acceleration of the crank pin; and let $a_{P'}$ be the acceleration of piston P'. The result of taking d^2/dt^2 of Eq. (19) and replacing $d\theta/dt$ by V_C/R and V_C^2/R by a_C is

$$a_{P'}/a_C = -\cos(\theta - \beta) + (r/L)(-2^2b_2\cos 2\theta + 4^2b_4\cos 4\theta - \ldots) + c[-2^2b_2'\cos 2(\theta - \delta) + 4^2b_4'\cos 4(\theta - \delta) - \ldots] \quad (20)$$

Maximum Errors

Let

$$e_2 = \sum(b_4 + b_6 + b_8 + \ldots) \quad (21)$$

$$E_2 = \sum(4^2b_4 + 6^2b_6 + 8^2b_8 + \ldots) \quad (22)$$

and let e_2' and E_2' be the same summations as given in Eqs. (21) and (22), respectively, with each b replaced by the corresponding b'. Hence, e_2' and E_2' are the same functions of p' as e_2 and E_2 are, respectively, of p. Values of e_2 and E_2, or e_2' and E_2', are given in Table 1.

If all terms beyond 2θ are neglected, the maximum errors in the first series of Eqs. (19) and (20) occur at $\theta = 90°$ and are equal to $-e_2$ and E_2, respectively. When all terms beyond $2(\theta - \delta)$ are neglected, the maximum errors in the second series of Eqs. (19) and (20) occur at $\theta - \delta = 90°$ and are equal to $-e_2'$ and E_2', respectively. Since θ and $(\theta - \delta)$ cannot both be $90°$ at the same time, the numerical value of the maximum errors when each series terminates with its double angle term are from Eqs. (19) and (20), respectively,

$$|\text{Max. error in } S'/R| < (r/L)e_2 + ce_2' \quad (23)$$

$$|\text{Max. error in } a_{P'}/a_C| < (r/L)E_2 + cE_2' \quad (24)$$

Approximate Formula for Piston Travel

The maximum error in either S'/R or $a_{P'}/a_C$ will be greatest for the cylinder nearest to $\beta = 180°$ because c, and hence p' also, will be largest for that cylinder (Tables 2 and 4). In modern radial engines, the maximum error as found from Eqs. (23) and (24) will be less than $^1/_5$ per cent and 3 per cent for S'/R and $a_{P'}/a_C$, respectively. Hence, it will be sufficiently accurate to let (see Eq. (19))

$$S'/R = q + \cos(\theta - \beta) + (b_2r/L)\cos 2\theta + b_2'c\cos 2(\theta - \delta) \quad (25)$$

To simplify Eq. (25), let γ and K be defined by the relations

$$b_2'c\sin 2\delta = K\sin 2\gamma \quad (26)$$

$$b_2r/L + b_2'c\cos 2\delta = K\cos 2\gamma \quad (27)$$

$$K^2 = (b_2'c\sin 2\delta)^2 + (b_2r/L + b_2'c\cos 2\delta)^2 \quad (28)$$

By means of Eqs. (26) and (27) and the relation $\cos 2(\theta - \delta) = \cos 2\theta\cos 2\delta + \sin 2\theta\sin 2\delta$, Eq. (25) becomes

$$S'/R = q + \cos(\theta - \beta) + K\cos(2\theta - 2\gamma) \quad (29)$$

By virtue of Eqs. (26) and (27)

$$\cot 2\gamma = [(b_2r/L)/(b_2'c)]\csc 2\delta + \cot 2\delta \quad (30)$$

Eq. (30) is the simplest relation for calculating 2γ. After 2γ is obtained, K can be found with greater facility from Eq. (26) than from Eq. (28).

Maximum Piston Travel

The value of θ which makes S' a maximum is found from $dS'/d\theta = 0$. This condition applied to Eq. (29) reduces to

$$2K\sin 2(A - x) - \sin x = 0 \quad (31)$$

in which

$$x = \theta - \beta,\ A = \gamma - \beta \quad (32)$$

Let x_1 be an approximate solution of Eq. (31), let d_1 be the increase in $\sin x_1$ when x_1 is increased $1'$ and let d_2 be the increase in $\sin 2(A - x_1)$ when $2(A - x_1)$ is increased $2'$. Then, a more accurate approximation to the solution of Eq. (31) is

$$x_2 = x_1 + [2K\sin 2(A - x_1) - \sin x_1]/(d_1 + 2Kd_2) \quad (33)$$

the last term being in minutes. Eq. (33) is based on the fact that $[2K\sin 2(A - x_1) - \sin x_1]$ is decreased or increased by the amount $(d_1 + 2Kd_2)$ according as x_1 is increased or decreased $1'$.

The most obvious approximate solution of Eq. (31) is

$$x_1 = A/(0.25/K + 1) = (\gamma - \beta)/(0.25/K + 1) \quad (34)$$

which results from replacing each sine in Eq. (31) by its angle in radians. Since K is non-dimensional, x_1 and $\gamma - \beta$ in Eq. (34) can be in degrees instead of radians. Practically all modern radial engines fall within the range: $K < 0.15$, $\gamma - \beta < 15°$. The error in using Eq. (34) will be less than $4.5'$ in this range and will be less than $2.2'$ within the smaller range: $K < 0.15$, $\gamma - \beta < 12°$. If Eq. (33) is used in addition to Eq. (34), the error for any modern radial engine will be only a small fraction of a minute.

After the θ for maximum S' has been determined, maximum S' can be found from Eq. (29), or more accurately from

$$S' = R\cos(\theta - \beta) + r\sqrt{(1 - p^2\sin^2\theta)} + l\sqrt{[1 - (p')^2\sin^2(\theta - \delta)]} \quad (35)$$

which results from Eqs. (4), (10), and (11).

Minimum Piston Travel

The value of x which makes S' a minimum is also found from Eq. (31). Since this value of x is in the vicinity of 180°, it will be desirable to let

$$x = 180° - y \tag{36}$$

which changes Eq. (31) into

$$2K \sin 2(A + y) - \sin y = 0 \tag{37}$$

The procedure for solving Eq. (37) is analogous to that already given for solving Eq. (31). The equations corresponding to Eqs. (33) and (34) are, respectively,

$$y_2 = y_1 + [2K \sin 2(A + y_1) - \sin y_1]/(D_1 - 2K D_2) \tag{38}$$

$$y_1 = A/(0.25/K - 1) = (\gamma - \beta)/(0.25/K - 1) \tag{39}$$

in which y_1 is an approximate solution of Eq. (37) and y_2 is a more accurate approximation than y_1. The last term of Eq. (38) is in minutes; D_1 is the increase in $\sin y_1$ when y_1 is increased 1′ and D_2 is the increase in $\sin 2(A + y_1)$ when $2(A + y_1)$ is increased 2′. Both y_1 and $\gamma - \beta$ in Eq. (39) can be in degrees instead of in radians. The error in using Eq. (39) increases rapidly as K or $\gamma - \beta$ increases, but will be less than 2.5′ for values of $K < 0.15$ and $\gamma - \beta < 15°$ not covered in Table 6.

The 51 values of y in Table 6 are accurate to the nearest minute. Values of y for intermediate values of K and $\gamma - \beta$ can be found from the following formula, which is valid for any two-way interpolation.

Table 6

Values of y in Minutes for Minimum Piston Travel

	Values of K							
$\gamma-\beta$	0.01	0.03	0.05	0.07	0.09	0.11	0.13	0.15
1°							65	90
3°					101	140	192	263
5°			74	115	166	229	312	421
7°		56	103	159	228	313	421	558
9°	22	72	131	201	287	391	518	673
11°	27	87	157	241	341	460	602	768
13°	31	101	183	278	390	521	673	844
15°	36	115	206	312	435	575	732	905

$$y_1 = y_0 + p_a a + p_b b + p_a p_b e \tag{40}$$

in which y_0 is any value in Table 6, a the increase in y from y_0 to next column to right with no change in rows, b the increase in y from y_0 to next lower row with no change in columns, $(a + b + e)$ the increase in y from y_0 to next column to right and next lower row, p_a the fractional distances between the columns, and p_b the fractional distance between the rows for the intermediate values in question. The error in using Eq. (40) and Table 6 will not exceed 2.5′. For example, an approximate value of y for $K = 0.146$ and $\gamma - \beta = 3.4°$ is $y_1 = 192 + 0.8 \times 71 + 0.2 \times 120 + 0.8 \times 0.2 \times 38 = 278.9'$, which is 0.6′ greater than the correct value.

Example: Given $R = 2.75$, $L = 10.875$, $l = 8.812$, $r = 2.1467$, $\beta = 80°$

$r/L = 0.1974$, $c = 0.98510$, $2\delta = 182°\ 46'$ (Tables 4 and 5)

$p = R/L = 0.2529$, $p' = Rc/l = 0.3074$ (Eq. (12))

$b_2 = 0.06427$, $b_2' = 0.07875$ (Table 1)

$b_2'c = 0.077577$, $(b_2 r/L)/(b_2'c) = 0.16354$

$\cot 2\gamma = 17.305$ (Eq. (30))

$2\gamma = 183°\ 18'$, $\gamma = 91°\ 39'$, $\gamma - \beta = 11°\ 39' = 11.65°$

$K = 0.06506$ (Eq. (26))

$b_0 = 0.06400$, $b_0' = 0.07827$ (Table 1)

$q = 3.895$ (Eq. (18))

$S'/R = 3.895 + \cos(\theta - 80°) + 0.06506 \times \cos(2\theta - 183°\ 18')$ (Eq. (29))

$x_1 = 2°\ 24'$ (Eq. (34))

$y_1 = 231' = 3°\ 51'$ (Eq. (40) and Table 6)

Max. S', $\theta = x + \beta = 82°\ 24'$ (Eq. (32))

Min. S', $\theta = 180° + \beta - y = 256°\ 9'$ (Eqs. (32) and (36))

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Book Review

Meteorological Glossary, by Meteorological Office, British Air Ministry; Chemical Publishing Company, Chicago, first American edition, 1940; 251 pages, $3.00.

The present edition of this book contains a number of revisions over the last edition, which appeared in 1930. It explains and describes all of the terms and concepts used in meteorology. An alphabetical arrangement is used throughout, with many cross-references.

There is a large section devoted to the equivalents of English terms in Danish, Dutch, French, German, Italian, Norwegian, Portugese, Spanish, and Swedish. Also the international definitions of cloud forms are used.

Many of the colloquial expressions referring to particular types of local weather are described by cross-references. Statistics, physics, chemistry, geology, and instruments are drawn upon wherever they refer to the study of weather conditions.

This will undoubtedly be a useful book for meteorologists, even though the extent of its usefulness in this country is limited somewhat by the fact that many of the tabular data are based on weather observations in Great Britain or the United Kingdom.

Circles of Strain

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ABSTRACT

A graphical construction for strains analogous to Mohr's Circles of Stress, is derived. Its application to the determination of principal strains from three strains at 45° is demonstrated. It is believed that a clearer concept of the relationships involved will be obtained thereby and the analysis of plane states of stress will be facilitated.

INTRODUCTION

MOHR'S Circles of Stress have been used for the solution of problems involving two and three dimensional states of stress.[1,3,9] A similar construction can be devised for the relationship between strains. By a comparatively simple graphical construction the state of strain obtained from three gage lines at 45° can be represented by a circle of strain, and the principal extensional and shearing strains and their directions can be determined. The graphical construction can be used as a basis for a very simple analytical solution, and can also serve as a check upon the results of computation. From the principal strains, the principal stresses can be computed. In addition, the stresses as determined from the measured strains can be used to obtain a Mohr's Circle of Stress, from which the principal stresses can be immediately obtained. The relation to previously published solutions will be indicated in the text.

MOHR'S CIRCLES OF STRESS

Considering a plane state of stress, defined by the given stresses σ_x, σ_y, τ_{xy}, and making $\sigma_z = \tau_{yz} = \tau_{xz} = 0$, Mohr's Circle of Stress[1,2,3] can be drawn (Fig. 1).

Tensile stresses are taken as positive. Shearing stresses are positive when the pair of conjugate shearing stresses on opposite faces form a clockwise couple.

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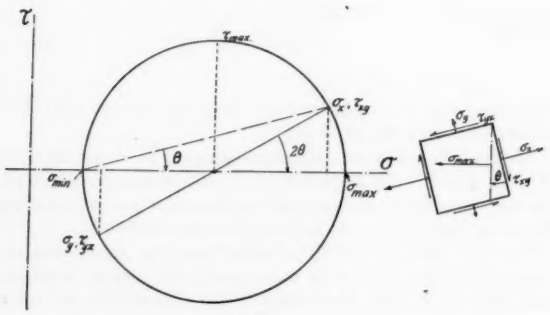

FIG. 1.

To construct the circle of stress the points σ_x,τ_{xy}, and σ_y,τ_{yx}, are plotted (noting that $\tau_{yx} = \tau_{xy}$, but is of opposite sign). The line joining these points will cut the σ axis at the center of the circle, and using the distance from the center to σ_x,τ_{xy} as a radius the circle is drawn. The radius of the circle will be $\tau_{max.}$, while the points at which the circle cuts the σ axis will be the principal stresses, σ_x and σ_y. From this construction the principal stresses and maximum shear can be easily computed. The distance from the origin to the center of the circle is $(\sigma_x + \sigma_y)/2$, while the radius,

$$\sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} = \tau_{max.} \tag{1}$$

Then

$$\sigma_{max.} = \frac{\sigma_x + \sigma_y}{2} + \tau_{max.} \tag{2}$$

$$\sigma_{min.} = \frac{\sigma_x + \sigma_y}{2} - \tau_{max.} \tag{3}$$

Also, the angle, θ, between the plane upon which σ_x acts and the plane upon which $\sigma_{max.}$ acts can be found from the circle as indicated, so that $\tan 2\theta = 2\tau_{xy}/(\sigma_x - \sigma_y)$, and since one proceeds in a clockwise direction from σ_x to $\sigma_{max.}$ in the circle of stress, one passes from the plane of σ_x to that of $\sigma_{max.}$ in the same sense.

The equation of Mohr's Circle of Stress is

$$\tau_{xy}^2 = \left(\frac{\sigma_{max.} - \sigma_{min.}}{2}\right)^2 - \left(\sigma_x - \frac{\sigma_{max.} + \sigma_{min.}}{2}\right)^2 \tag{4}$$

CIRCLES OF STRAIN

The general relations between stress and strain are[1]

$$\left.\begin{aligned} \sigma_x &= 2G\,[\epsilon_x + e/(m-2)] \\ \sigma_y &= 2G\,[\epsilon_y + e/(m-2)] \\ \sigma_z &= 2G\,[\epsilon_z + e/(m-2)] \\ \tau_{xy} &= G\gamma_{xy} \\ \tau_{xz} &= G\gamma_{xz} \\ \tau_{yz} &= G\gamma_{yz} \end{aligned}\right\} \tag{5}$$

Where $e = \epsilon_x + \epsilon_y + \epsilon_z$ and G (shearing modulus of elasticity) $= mE/2(m+1)$, where m = Poisson's number. For the plane state of stress, $\sigma_z = 0$; therefore

$$\epsilon_z + e/(m-2) = 0$$

$$(m-2)\,\epsilon_z + \epsilon_x + \epsilon_y + \epsilon_z = 0$$

$$\epsilon_z = -(\epsilon_x + \epsilon_y)/(m-1)$$

$$e = +\frac{m-2}{m-1}(\epsilon_x + \epsilon_y) \tag{6}$$

Therefore

$$\sigma_x = 2G\left(\epsilon_x + \frac{\epsilon_x + \epsilon_y}{m-1}\right) = \frac{2G}{m-1}\left(m\epsilon_x + \epsilon_y\right) \tag{7}$$

$$\sigma_y = \frac{2G}{m-1}(m\epsilon_y + \epsilon_x) \tag{8}$$

$$\frac{\sigma_x - \sigma_y}{2} = G(\epsilon_x - \epsilon_y) \tag{9}$$

$$\frac{\sigma_x + \sigma_y}{2} = \frac{G(m+1)}{m-1}(\epsilon_x + \epsilon_y) \tag{10}$$

Also, generalizing Eq. (5),

$$\sigma = 2G[\epsilon + e/(m-2)] \tag{11}$$

where σ and ϵ are stress and corresponding strain in any one direction. Substituting value of e from Eq. (6)

$$\sigma = 2G\left(\epsilon + \frac{\epsilon_x + \epsilon_y}{m-1}\right) \tag{12}$$

Substituting Eqs. (5), (9), (10), and (12) in Eq. (4), noting that $\tau = G\cdot\gamma$ and that ϵ_x and ϵ_y are now to be the principal strains,

$$G^2\gamma^2 = G^2(\epsilon_x - \epsilon_y)^2 - G^2\left\{\left[2\epsilon + \frac{2(\epsilon_x + \epsilon_y)}{m-1}\right] - \left[\frac{m+1}{m-1}(\epsilon_x + \epsilon_y)\right]\right\}^2$$

$$\gamma^2 = (\epsilon_x - \epsilon_y)^2 - [2\epsilon - (\epsilon_x + \epsilon_y)]^2 \quad (\gamma/2)^2 = (\epsilon_x - \epsilon_y)^2 - [\epsilon - (\epsilon_x + \epsilon_y)]^2 \tag{13}$$

Eq. 13 is of the same form as Eq. 4, so that by comparison one may conclude that a circle of strain in which the abscissae are extensional strains and the ordinates are half the shearing strains will represent the state of strain. This circle is different from the dyadic circle of Westergaard[2] and Osgood.[5] The same constructions can be applied to three dimensional stress and strain problems, by drawing the circles for each of the planes containing principal stresses or strains.

Example 1: Proceeding in a clockwise direction 45° apart, $\epsilon_1 = +235$, $\epsilon_2 = +65$, $\epsilon_3 = -55$. Lay off points 1, 2, and 3 on the ϵ axis at distances, +235, +65, −55 from origin in Fig. 2. Bisecting the distance between points 1 and 3 (points corresponding to strains 90° apart) the center of the circle, C, is $[235 - (-55)]/2 = 145$ units from 3 and 1. The distance from 2 to C is $145 - (65 + 55) = 25$ units and this is laid off vertically downward from 1 to point A. If C is to the left of 2, this distance is laid off upward from 1. CA is the radius and the circle of strain is now drawn. Point A represents the state of strain, $\epsilon_1 = +235$, $\gamma = 2(-25) = -50$; point B the state of strain, $\epsilon_3 = -55$, $\gamma = +50$; point D the state $\epsilon_2 = +65$, $\gamma = -290$. Note that points A, D, B, corresponding to ϵ_1, ϵ_2, ϵ_3 are 90° apart as one proceeds in a clockwise direction from ϵ_1. If the distance 2–C is laid off incorrectly, the sequence becomes reversed, and the error can be detected. The radius of the circle is $\sqrt{(145)^2 + (25)^2} = 147.14$. $\epsilon_{max.} = 90 + 147.14 = +237.14$, and $\epsilon_{min.} = +90 - 147.14 = -57.14$. The angle θ is found from $\tan 2\theta = 25/145$ or $2\theta = 9° -47'$; $\theta = 4° 53'.5$. In the circle one proceeds in a counter-clockwise direction from A to $\epsilon_{max.}$, therefore the maximum strain will be located by going in a counter-clockwise direction from the line of strain ϵ_1. The direction of $\epsilon_{min.}$ is at right angles to that of $\epsilon_{max.}$ and the maximum shearing strains are at 45° to $\epsilon_{max.}$ and $\epsilon_{min.}$. The maximum shearing strain is $\gamma_{max.} = 2 \times 147.14 = 294.28$.

This problem is the same as that in Sibert's[8] paper, with the same results. Note that K in that paper and in Hill's paper[7] is merely half the maximum shearing strain. Also, the use of the cosine curve[7,8] is unnecessary and the directions of the strains can be found by inspection without special rules.

If Poisson's ratio is 3/10 or $m = 10/3$, by Eq. (6)

$$e = (4/7)(237.14 - 57.14) = +102.86$$

and

$$e/(m-2) = (102.86/4) \times 3 = +77.14$$
$$G = 10E/26 = .385E$$
$$\sigma_{max.} = .770E(237.14 + 77.14) = +242.0E$$
$$\sigma_{min.} = .770E(-57.14 + 77.14) = +15.4E$$
$$\tau_{max.} = .385E(294.28) = \pm 113.3E$$

The stresses could also be calculated directly from the strains:

$$\sigma_1 = .770E(235 + 77.14) = +240.35E$$
$$\sigma_2 = .770E(65 + 77.14) = +109.45E$$
$$\sigma_3 = .770E(-55 + 77.14) = +17.05E$$

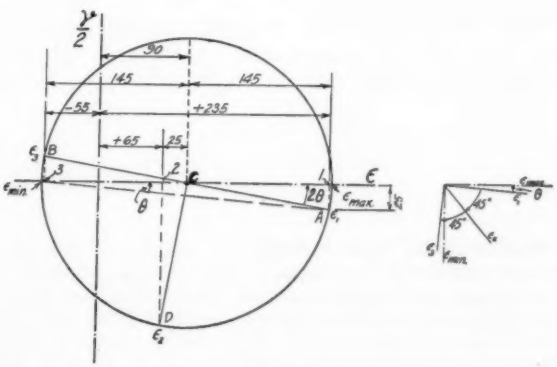

FIG. 2.

Drawing Mohr's Circle of Stress, in the same manner as the previous circle of strain, Fig. 3 results.

$$\tau_{max.} = \sqrt{111.65^2 + 19.25^2} = \pm 113.3$$
$$\sigma_{max.} = 128.7 + 113.3 = +242.0$$
$$\sigma_{min.} = 128.7 - 113.3 = +15.4$$

$\tan 2\theta = 19.25/111.65$; $\theta = 4^\circ\ 53'.5$ (counter-clockwise from σ_1 to $\sigma_{max.}$).

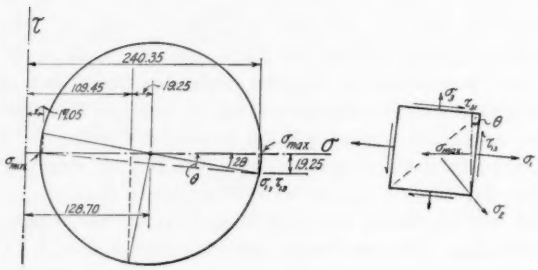

FIG. 3.

The presentation of Mohr's Circle of Stress in Niles and Newell "Airplane Structures," differs slightly from the one here given. The two methods of presentation can be co-related by the construction shown in Fig. 4.

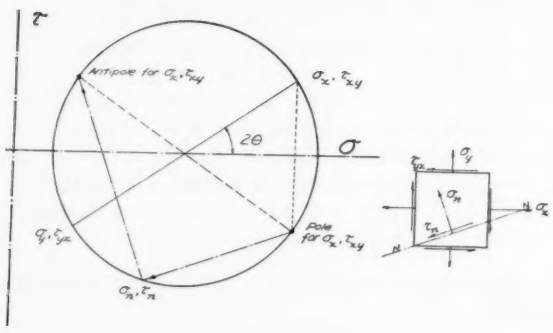

FIG. 4.

The point on the circle which is on the opposite side of the σ axis and symmetrically located with respect to that axis, corresponding to σ_x, τ_{xy} will be called the "Pole" for σ_x, τ_{xy} and the point diametrically opposite the pole will be termed the "Anti-pole." If one wishes to determine the state of stress on plane N–N shown in the elementary prism, a line is drawn parallel to NN through the pole and one perpendicular to NN through the anti-pole. Note that σ_x is now oriented in a horizontal direction in the figure. The point σ_n, τ_n so located gives the state of stress on NN and the shearing force vector and normal force vectors are parallel in the two figures as indicated. The same construction can be used for the circles of strain.

NOMENCLATURE

- σ = normal unit stress
- τ = shearing unit stress
- σ_x, σ_y, σ_z = normal stress in X, Y, Z directions (orthogonal co-ordinate system)
- τ_{xy} = shearing stress parallel to Y axis on plane normal to X axis (similarly for others)
- ϵ = unit extensional strain (subscripts similar to those for σ)
- γ = unit shearing strain (subscripts similar to those for τ)
- e = unit dilatation
- G = shearing modulus of elasticity
- E = Young's modulus
- m = Poisson's number ($1/m$ = Poisson's ratio)

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Book Review

Equator South Equator North, by JACQUELINE WALKER; privately published, San Francisco, 1939; 207 pages, illustrated.

Unfortunately for those who are planning to visit South America by Pan American Airways, this book was published privately and is not generally available. It is a vivid account of Mrs. Walker's trip and gives evidence of her keen power of observation and discrimination. She not only describes her experience in the air, but gives in a style which reminds one of that of Anne Lindbergh, her impressions of the social and family life in the cities she visited. Having more than a tourist's interest in things aeronautical, resulting from active participation in the development of the aircraft industry on the Pacific Coast, she combines in this book a description of the experiences of a cultured tourist and a traveler who apparently was shown much special attention.

Light Aero Engines of Europe—Present and Future*

D. R. POBJOY

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IN defining "light aero engines," an upper limit of 300 hp. may be chosen to include all sizes of engines suitable for privately owned aeroplanes, ab-initio school machines, and light twin-engined commercial aircraft used for local unsubsidized air lines and charter work. Essential features of the group, more so than for larger powers, are that the engines must be comparatively inexpensive, able to run for long periods with the minimum of skilled maintenance, and easy and cheap to repair.

These qualities are rather more important for the sizes in question than low weight per hp. or fuel economy. Great speeds cannot be expected with the powers available, so that compared with larger machines, inferior power loadings allied with lower wing loadings are permissible. Moreover, for private and training machines at any rate, the payload percentage of the total weight is unimportant compared with sturdiness and cheapness of construction of the aircraft. A very light engine would of course improve the payload and (or) range, but, having sacrificed some to make the aeroplane simple and strong, it is logical to sacrifice a little more and treat the engine in the same way.

The problem really boils down to a nice balance between the commercial and engineering aspects; that is, between the sales demand and the technique of the moment. Future development must obviously move toward improving the power/weight ratio of the loaded machine accompanied by a reduction rather than an increase in purchase price and operating costs.

Comparison of Various Engine Layouts

In selecting a layout for manufacture, the first problem to settle is the probable output which can be sold. This estimate affects (a) the permissible prime cost of manufacture, (b) the allowance for tooling-up, and (c) the development expenditure warranted.

The next question is whether the engine shall have a geared or directly driven airscrew. The former is invariably used in large engines, the latter usually adopted for the sizes under discussion. For direct drive engines, considerations of airscrew efficiency limit the crankshaft speed (during climb) to about 2600 r.p.m. in the smaller sizes and to about 2000 r.p.m. for the upper end of the range. Ignoring designed variations in b.m.e.p., the r.p.m. being thus fixed, irrespective of engine type, the power available must be simply proportional to the engine-swept volume.

Three popular arrangements of such direct drive engines are:

(1) Inverted 4- or 6-in-line, with pushrod operated valves.

(2) Flat twin or four.

(3) 5- or 7-cylinder radial.

Group (1) are the cheapest to make, and the easiest to install, and cowl neatly. They are probably the heaviest.

Group (2) are lighter than Group (1) but, with detachable cylinders, more expensive. The weight saved in the shorter crankshaft and crankcase may be put back by making the cylinders and crankcase in one or two cast-iron pieces, with a considerable saving in manufacturing cost. Engines in this group are easy to install, but the cowling and cooling baffles are probably a little more expensive than for Group (1).

Group (3) engines are necessarily the lightest, but probably the most expensive to make and the most difficult to cowl neatly and cheaply. The bare engine may be no more expensive than types in Group (1); however, the cooling baffles and exhaust manifold are certainly more complicated than for an in-line engine, not to mention the exterior cowling. Moreover, the modern demand for the minimum of maintenance renders essential the total enclosure of the valve gear with, for all but low outputs, some kind of automatic oil metering or circulating system.

The main lubricating system of radial engines must of necessity include a scavenge pump. This component is often successfully omitted from in-line engines, the oil draining by gravity back to the tank.

As regards the main portions of the engines, the crankcase of the 5- or 7-cylinder radial is cheaper for material but about the same for machining as that of the 4- or 6-in-line engine, respectively. There is not much to choose between the cost of the roller bearings of the radial, properly supported in separate housings, and that of the more numerous plain bearings of the in-line engine. The radial crankshaft, if of the divided

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* Pressure for space in the Journal prevents publication of Mr. Pobjoy's complete article on this subject. The account given here consists of excerpts from the paper as prepared by the author for presentation at the International Congress of the Aeronautical Sciences, scheduled to be held on September 11 to 16, 1939, in New York. Because of the international situation, the Congress was postponed until 1941. A summary of the paper was presented at the Power Plants Session, Eighth Annual Meeting, I.Ae.S., New York, January 24, 1940.

type, is perhaps a little more costly than a 4-in-line but a little less than a 6-in-line shaft. All these comparisons are of course based on equal total engine displacement.

The connecting-rod assembly of the 5- or 7-cylinder radial is undoubtedly more costly, by the time it is assembled on the crankpin, than the plain connecting-rods of the 4- or 6-in-line engine, respectively; especially if advantage is taken of the room available in the in-line engine but denied in the radial to make the rods of comparatively bulky light alloy forgings unmachined on the flanks, and of dispensing with a small-end bushing. The radial rods must be of steel, machined all over with a pressed-in bush, properly secured, at the small end. The cam drum of the radial and its driving gears cost about the same as the camshaft and gears of the in-line engine.

In general, it might be said that radials cost less for material but more for machining, fitting and assembly than do the equivalent in-line engines. In the author's experience the last two items are of greater importance with the comparatively small outputs of light aero engines than they would be with larger quantities, owing to the difficulty of organizing and tooling up for flow assembly.

In the matter of frontal area the in-line engine has the advantage of the radial, especially with these direct drive engines.

Geared Engines

If reduction gear to the airscrew is provided, the crankshaft r.p.m. is no longer dictated by the airscrew efficiency and may be selected to suit the engine layout or its operating conditions. This circumstance changes the picture of the relative merits of the various types.

The weight of the reduction gearing per hp. transmitted is substantially independent of the engine arrangement. Moreover, for equal big-end bearing loadings the in-line or Vee engine may turn faster than the radial, thus still further reducing the margin. However, in this case the pistons and valve gear of the in-line engine must run faster than those of the radial. This is no hardship for the pistons, as a speed of say 4000 r.p.m. for a piston of 4-inch bore by 5-inch stroke can easily be accommodated with good durability. The valve gear, however, requires consideration at these higher speeds, and overhead or rather underhead camshafts are desirable.

In short, it may be said that geared in-line engines should and are safely able to run faster than geared radials, thereby compensating to some extent for their greater specific weight/displacement; but they should have underhead camshafts, while the radials may use pushrod operation. The underhead camshaft of the in-line or Vee engine makes a neat arrangement easily lubricated and having high durability and freedom from maintenance, while the pushrod system is the only practical one for radials. On the other hand, the underhead camshaft undoubtedly adds to the cost of the engine. Thus, in reducing the power/weight difference of the two types, the cost margin has also been narrowed.

The author has found that the radial engine of not less than seven cylinders is somewhat easier to gear than an in-line-Vee engine owing to the very small inertia torque and to the reduced chances of torsional vibration periods occurring in the running range.

Small single-line engines of four or six cylinders while more liable to torsional vibration periods are further handicapped by the cyclic variations in driving torque. In fact, the only example known to the author of a geared 4-in-line is an experimental engine of 100 hp. now under construction by his firm in which the torque variation is taken care of by a substantial rubber driving connection built into the airscrew hub. A satisfactory geared flat four was made by the Praga Company of Czecho-Slovakia.

A simple solution of the problem of increasing the number of power strokes per minute from a given number of cylinders, without recourse to a reduction gear, would be to employ the two-stroke cycle. In spite of the high output, the piston speed would be low and the durability very high. A blower is necessary for scavenging purposes, and its gearing may be just as troublesome and expensive as a reduction gear. The fuel supply arrangement must be different from and more expensive than that of conventional 4-stroke engines. The two-stroke cycle is thus unlikely to save manufacturing costs, but it has other possibilities as mentioned below.

Another scheme for avoiding a reduction gear might be to ground-boost heavily a simple direct-drive 4-stroke engine by a centrifugal supercharger or possibly a displacement blower in the smaller sizes. The centrifugal type is disproportionately expensive for small engines, because the compression ratio being a function only of the impeller tip speed, the unit must either be large compared with the engine or rotate at excessively high speed. High mean effective pressures thus developed at crankshaft speeds low for the size of engine may introduce troubles with the crankcase, bearings and cooling owing to high gas pressures and low inertia forces. A better compromise is to be content with a modest ground-boost and have a reduction gear as well.

Future Developments

Civil aviation of the sort catered for by the sizes of engines under discussion requires development in the directions of reduced costs, reduced hazards and greater usefulness.

The small aero engine must accordingly develop in the directions of more power per cubic inch of piston displacement accompanied by lower manufacturing

and repair costs, and the elimination of maintenance attention in service between infrequent major overhauls.

During the past two years the author has considered various solutions of the problem of the small engine. First of all he designed a highly developed geared and moderately boosted 7-cylinder radial of 236 cubic inches capacity and a weight of 195 lbs., with a normal rating of 140 b.hp. at 3600 r.p.m. Its manufacture was not proceeded with as it was considered to be too expensive.

A geared 4-cylinder and a geared V-8, both inverted and having underhead camshafts, of the same bore and stroke and rated at 100 and 200 b.hp., respectively, were then considered. For the larger engine the V-8 arrangement was selected as being lighter and better than six cylinders in line, although the duplication of the camshafts increases the cost. The oil circulating arrangements for the camshaft casings involves some complication. Moreover, the use of separate steel cylinders entails a fairly elaborate system of camcase/cylinder-head construction.

To meet all these objections, it was decided to use single sleeve valves. In adopting the usual practice of allowing the sleeves to run direct in aluminum barrels, the opportunity was taken to cast all of the cylinders in one piece with the crankcase. The not inconsiderable foundry difficulty once overcome, the machining and assembly costs are greatly reduced as compared with conventional engines, accompanied by the gains in power, economy, durability, silence, etc., recognized as attributes of the sleeve-valve engine. The sleeves are nitrogen-hardened inside and out. The elliptical motion of the sleeve, by avoiding the "dwell" of the piston rings at the top and bottom of the stroke, removes one of the main causes of cylinder wear.

The foundry problem, especially severe in the case of the V-8 model, has been solved. More than adequate fin area for the rated power has been provided. The V-8 is of 362 cubic inches; the standard model has a medium-speed blower giving a normal ground-level power of 240 b.hp. at 3600 r.p.m. (1800 r.p.m. airscrew speed). The total weight (exclusive of constant-speed airscrew) is 345 lbs. The altitude model has a higher-speed blower and is rated at 8000 feet. The 90 degree balanced crankshaft gives excellent balance, while the even driving torque and the small inertia torque of the short stiff shaft are all favorable to the main reduction gear. The blower drive includes a simple vibration damper eliminating periods in the crankshaft.

The 4-cylinder model is aspirated, rated at 100 hp. at 3600 r.p.m., and geared down 2 to 1. A substantial rubber coupling suitably damped is incorporated in the fixed airscrew hub to take care of the crankshaft torque fluctuation. The total weight is 195 lbs.

The large breathing capacity of a sleeve valve and its ability to withstand exhaust back pressure should make possible the construction of two-stroke engines of high output and of compounded engines. Sleeve-valve Diesel engines are particularly attractive in all sizes.

Book Review

The Aviation Business; from Kitty Hawk to Wall Street, by ELSBETH E. FREUDENTHAL; The Vanguard Press, 1940; 345 pages, $3.00.

The author of this book evidently believes that the aircraft industry of the United States should not only be nationalized, but patterned after the Soviet factories where the "profit motive" is removed. The author refers to herself as a "securities analyst with long experience in Wall Street." Apparently she has made a specialized study of the many investigations of the aircraft industry and has used certain parts of this record as a basis for discrediting the expanding American aircraft industry. Possibly the volume may be useful as nationalization propaganda. At any rate, there is no reference to the tragic situation France was in as a result of her experiment in nationalization; no statement regarding the results of the "shadow factory" scheme in England and, of course, no comment on the devastating effects that political influence would exert in Government-owned factories. From the point of view of research and engineering, nationalization of the industry would be ruinous. It would prevent that freedom of experimentation and design which has characterized the growth of our industry. While the author admits that those who have had experience with airplane manufacturing are the ones who have brought it to its present state of world favor, apparently she now would turn the industry over to the Army and Navy or to political appointees to manage; she extends this even to the air transport companies and refers to the Trans-Canada Airlines as an example of the plan. She does not refer to the fact that the first thing done by the Canadian Railway Officials, who really control the company, was to engage a complete American staff recruited from our industry and transportation companies and to turn the entire management over to them. Likewise, no comparison is made as to the extent and excellence of American air transport companies with those of other countries, many of which are Government controlled. The aircraft industry is based upon sound engineering and progressive production methods. Any plan, whether it be nationalization, socialism or communism which prevents freedom of initiative and stifles competition, would soon bring American airplanes down to the inferior performance of those of some other countries.

LESTER D. GARDNER

Frequency and Vibration Problems of Rotors

R. H. PREWITT AND R. A. WAGNER

Kellett Autogiro Corporation

INTRODUCTION

IN proceeding from fixed wing aircraft to rotating wing aircraft, there are not only new and complicated aerodynamic and stability problems but also new vibration problems to be met and solved. These vibration problems have undoubtedly been a major item in retarding the development of rotorcraft.

Theoretical studies of rotorcraft vibration and frequency problems, which were initiated about two years ago by the Kellett Autogiro Corporation, have culminated in this paper. This study has been confined to the frequency problems which are peculiar to hinged rotor blades. It is felt that rigid-blade rotor construction may be analyzed by substantially the same methods as are available for analyzing propellers and, therefore, no consideration has been given to this specialized type in this paper.

When a rotorcraft is operating in horizontal flight, the airflow over the blades on the advancing side of the rotor is considerably greater than the airflow over the retreating side. This unsymmetrical flow of air over the blades, in combination with the non-uniform flow of air through the rotor disc, causes the blades to rise and fall during each revolution of the rotor. In addition, the blades flex in bending in the plane of flapping and oscillate about the vertical hinges with a frequency of one cycle for each revolution of the rotor.

PENDULAR FREQUENCY ABOUT THE VERTICAL HINGE

Simple Case

In calculating the natural frequency of a blade about the vertical pin, use is made of the standard frequency equation for rotational oscillations of this sort.

$$F = (60/2\pi)\sqrt{k/I} \text{ cycles per minute} \qquad (1)$$

Referring to Fig. 1, let U_0 be the mass density per unit length of blade at the vertical hinge, and let U_R be the mass density per unit length at the tip, and assume a linear variation in density from root to tip.

The general mass density per unit length may be expressed as

$$U_r = U_0 + (r/R)(U_R - U_0) \qquad (1a)$$

The centering moment about the vertical pin due to dm is

$$\text{Elemental Moment} = (C.F.)[er\theta/(e + r)] \qquad (1b)$$

for small values of θ.

If ω is the angular velocity of the rotor

$$C.F. = \omega^2(e + r)dm = \omega^2(e + r) \times [U_0 + (r/R)(U_R - U_0)]dr \qquad (1c)$$

$$\text{Moment } V.P. = \omega^2 e\theta \int_0^R r[U_0 + (r/R)(U_R - U_0)]dr$$

$$= (\omega^2 e\theta R^2/3)[(U_0/2) + U_R] \qquad (1d)$$

$$\text{and } k = M_{V.P.}/\theta = (\omega^2 eR^2/3) \times [(U_0/2) + U_R] \qquad (1e)$$

$$I = \int_0^R r^2 dm = (R^3/4)(U_R + U_0/3) \qquad (1f)$$

Hence, the ratio between frequency of oscillation and rotor r.p.m. is

$$F/N = \sqrt{(2e/R)(U_0 + 2U_R)/(U_0 + 3U_R)} \qquad (1g)$$

For a uniform blade, $U_0 = U_R$, and the ratio becomes

$$F_U/N = \sqrt{3e/2R} \qquad (1h)$$

Actually, the frequency ratio for tapered blades is not greatly different than the frequency of blades having uniform mass distribution. For example, in a linearly varying blade having a mass density at the root of 2.5 times the mass density at the tip, the blade frequency is increased by only 4.4 per cent, and with a taper to zero mass at the tip the frequency is increased by 15.4 per cent over that of a blade having uniform mass distribution.

Additional Self-Centering Springs

The effect of springs incorporated at the vertical pin so as to cause self-centering of the blade, independent

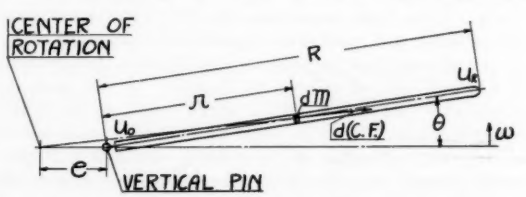

FIG. 1. Plan view of blade showing centering force when the blade is displaced in plane of rotation.

Presented at the Second Annual Rotating-Wing Aircraft Meeting, sponsored by the Philadelphia Section, I.Ae.S., December 1, 1939.

of the centrifugal force, is of course to increase the natural frequency of oscillation of the blade. Since the centering moment will be increased because of the addition of springs, the spring characteristic of the blade will be increased in a like ratio. Therefore the frequency will be increased by the square root of the increase in centering moment. The foregoing statements imply a constant spring characteristic, that is, a linear spring system, in which the centering moment is proportional to the displacement. If such is not the case, and in most cases it is not, the problem becomes more difficult. However, it is always possible to solve for the frequency due to the centering springs alone, generally by means of one or two graphical or numerical integrations.[1]

The approximate final frequency is equivalent to the square root of the sum of the squares of the various frequencies involved.

$$F_V = \sqrt{F_{C.T.}^2 + F_S^2} \qquad (2)$$

where F_V is the natural frequency of the blade about the vertical axis, $F_{C.T.}$ is the natural frequency due to the centrifugal force, and F_S that due to centering springs. If the springs are non-linear, F_V will depend upon amplitude, and hence F is dependent not only on the r.p.m. of the rotor, but also upon the amplitude of oscillation of the blade. This characteristic of frequency may be used in many cases to limit the amplitude of oscillation due to resonant conditions.

Pendular Frequency about Horizontal Pin

Simple Case

The natural frequency of the blade about the horizontal pin is dependent upon several items of construction. It depends upon the distance from the horizontal pin to the axis of rotation, and upon the angle between the horizontal hinge centerline and the spanwise axis of the blade. The simplest case for analysis is that in which the horizontal hinge lies on the axis of rotation, and is perpendicular to the spanwise axis of the blade.

Referring to Fig. 2, consider a particle of mass dm at a distance r along the blade. ($h = 0$, since the horizontal hinge was assumed to lie on the axis of rotation.) The centrifugal force on the particle $= \omega^2 r \cos \beta dm$, and the moment about the horizontal hinge due to centrifugal force $= \omega^2 r^2 \sin \beta \cos \beta dm$. Since the amplitude of flapping will usually be less than 5°, $\sin \beta \approx \beta$ and $\cos \beta \approx 1$, so that the moment about the horizontal hinge $\approx \omega^2 r^2 \beta dm$. This moment acts as a spring tending to return the blade to neutral, so that the characteristic of the moment $k = \omega^2 r^2 dm$, and $I = r^2 dm$. Substituting in Eq. (1)

$$F_N = (60/2\pi)\sqrt{\omega^2 r^2 dm / r^2 dm} = 60\omega/2\pi =$$

$$N \text{ or } F_N/N = 1 \qquad (3)$$

Thus, for the simple case evaluated, the pendular frequency of the blade in flapping is the same as rotor speed.

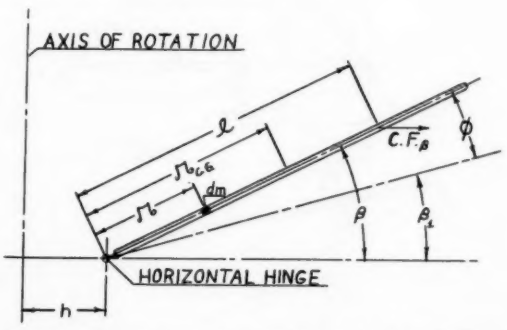

Fig. 2. Elevation view of blade showing centrifugal forces acting when the blade is in coned positions.

Flapping Hinge Moved Outboard

The physical effect of moving the flapping hinge away from the axis of rotation is to increase the centrifugal force, and hence the restoring moment characteristic is also increased, while the moment of inertia of the blade about the horizontal pin remains the same. Thus, an increase in the natural frequency over that with the hinge on the axis of rotation is to be expected.

The centrifugal force with the flapping hinge on the axis of rotation is equal to $\omega^2 m r_{C.G.}$. The centrifugal force with the flapping hinge at h is equal to $\omega^2 m \times (r_{C.G.} + h)$. The increase in centrifugal force is $\omega^2 mh$, and the percentage increase over the centrifugal force with the flapping hinge at the axis of rotation is $\omega^2 mh / \omega^2 m r_{C.G.} = h/r_{C.G.}$

The moment about the flapping hinge will increase proportionately, so that the ratio of flapping frequency to rotor speed is:

$$F/N = \sqrt{1 + h/r_{C.G.}} \qquad (4)$$

Since $h/r_{C.G.}$ in a practical design would probably not be greater than 0.05, the natural frequency will increase only $2^1/_2$ per cent over the natural frequency with the flapping hinge on the axis of rotation.

Effect of Coning

Average coning also has an effect upon the natural frequency of the blade in flapping. The physical effect of coning is to reduce the centrifugal force, since all the elements of the blade move closer to the axis of rotation when coning is present. Hence a reduction in the natural frequency is expected.

Referring to Fig. 2, consider the blade to be oscillating by flapping about a neutral position coned upward $\beta_1{}^0$ above the plane of rotation.

The air load moment about the flapping axis will be equal in magnitude and opposite in direction to the centrifugal force moment when the blade is coned to its neutral position. Furthermore, since the free, un-

damped frequency is being analyzed, and the amplitude of flapping motion is small, the air load moment may be assumed constant.

The net moment acting on the blade is then

$$M = l(C.F._{\beta} \sin \beta - C.F._{\beta_1} \sin \beta_1) \tag{5a}$$

The centrifugal force acting on the blade is

$$C.F._{\beta} = \omega^2 m r_{\beta} = \omega^2 m(h + r_{C.G.} \cos \beta) \tag{5b}$$

so that

$$M = \omega^2 ml[h(\sin \beta - \sin \beta_1) + r_{C.G.} (\cos \beta \sin \beta - \cos \beta_1 \sin \beta_1)] \tag{5c}$$

Since $\beta - \beta_1 = \phi$ is small (of the order of 5° or less) so that $\sin \phi \approx \phi$ and $\cos \phi \approx 1$,

$$M = \omega^2 ml(h \cos \beta_1 + r_{C.G.} \cos 2\beta_1)\phi \tag{5d}$$

$$k = M/\phi = \omega^2 ml(h \cos \beta_1 + r_{C.G.} \cos 2\beta_1) \tag{5e}$$

The moment of inertia of the blade $= mlr_{C.G.}$ where l is the distance from the flapping hinge to the center of gravity of the blade.

Referring to Eq. (1), the ratio between flapping frequency and rotor speed:

$$F_F/N = \sqrt{(h/r_{C.G.}) \cos \beta_1 + \cos 2\beta_1} \tag{5f}$$

The ratio F_F/N is plotted for $h/r_{C.G.} = 0.05$ in Fig. 3.

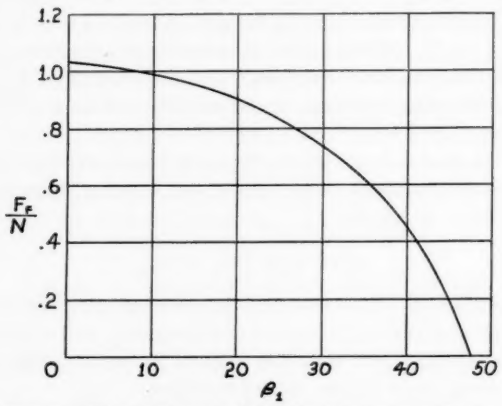

FIG. 3. Change in natural flapping frequency ratio resulting from average coning angle.

This curve shows that in the practical range of average coning, $\beta_1 < 10°$, the undamped natural flapping frequency of the blade approximates the r.p.m. of the rotor.

Cocked Horizontal Hinge

The analysis of the case where the horizontal hinge is not perpendicular to the spanwise axis of the blade differs from the cases previously considered in that the centering moment and the moment of inertia must be referred to the flapping axis; these quantities change with changes in the angle of the flapping hinge. (See Fig. 4.)

Neglecting all effects of the surrounding air on the blades, such as would be the case if the blade were replaced by a thin heavy rod, the natural frequency is independent of the angle of flapping axis. This is due to the fact that both the moment of inertia and the restoring moment due to centrifugal force vary as $\cos^2 \delta_3$.

However, a much different situation exists when considering the effect of the air upon the oscillation of a blade. As the blade is displaced upward, the angle of attack of each element is decreased. This decrease is twofold. First, there is a decrease due to the geometry of the system; that is, the blade itself assumes a decreased angle of attack. Second, there is a decrease due to the upward velocity of flapping. This second effect is proportional to the velocity of flapping, and hence is a damping effect. The two effects will be evaluated separately.

(a) *Neglecting Damping*

The decrease in angle of attack results in less lift on the blade, and consequently less moment about the δ_3 axis. This is the same as increasing the centering moment, and results in an increase in natural frequency.

With reference to Eq. (1), $k = k_1 =$ total moment per unit angular displacement about the flapping axis. This moment is the sum of the air load moment and the centrifugal force moment.

The air load moment per unit displacement $k_{A.L.}$ may be derived as follows: Referring to Fig. 4, the lift dL on an element of the blade is

$$dL = C_L(\rho/2)(\omega r)^2 C dr \tag{6a}$$

and the moment about the δ_3 axis due to that elemental lift is

$$dM = C_L(\rho/2)\omega^2 C \cos \delta_3 r^3 dr \tag{6b}$$

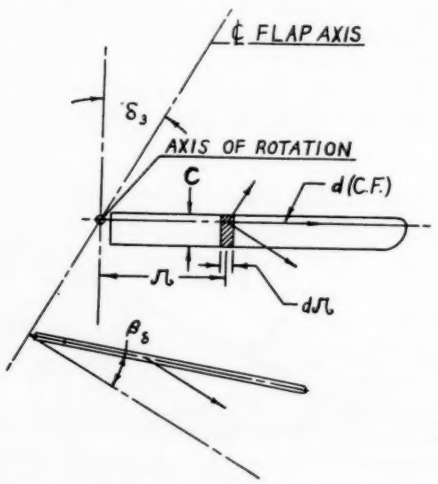

FIG. 4. Plan and elevation views of blade having cocked horizontal hinge.

Evaluation of C_L:

Let $\Delta\alpha$ = change in angle of attack with change of β_δ about the flapping axis.

$$\text{Tan } \Delta\alpha = (\beta_\delta r \cos \delta_3)/(r/\tan \delta_3) = \beta_\delta \cos \delta_3 \tan \delta_3 = \Delta\alpha \tag{6c}$$

It may be assumed without loss of generality, that $C_L = 0$, when $\beta_\delta = 0$. Then $C_L = a\,\Delta\alpha$ where a = slope of lift curve. Hence

$$dM = a\beta_\delta(\rho/2)\omega^2 C \cos^2 \delta_3 \tan \delta_3 r^3 dr \tag{6d}$$

and integrating over the entire blade from 0 to R,

$$M_{A.L.} = a\beta_\delta(\rho/2)\omega^2 C \cos^2 \delta_3 \tan \delta_3 R^4/4 \tag{6e}$$

from which

$$k_{A.L.} = M_{A.L.}/\beta_\delta = a(\rho/2)\omega^2 C \cos^2 \delta_3 \tan \delta_3 R^4/4 \tag{6f}$$

The centrifugal force moment per unit displacement $k_{C.T.}$ about the flapping axis may be derived as follows: Referring again to Fig. 4, the differential moment about the flapping axis due to an elemental mass at r is

$$dM = d(C.F.)r\beta_\delta \cos^2 \delta_3 \tag{6g}$$

$$= \omega^2 \beta_\delta \cos^2 \delta_3 U r^2 dr \tag{6h}$$

Assume the blade has uniform distribution of mass, so that U is constant, and integrate over the entire blade,

$$M_{C.F.} = \omega^2 \beta_\delta \cos^2 \delta_3 UR^3/3 = \omega^2 \beta_\delta \cos^2 \delta_3 I_0 \tag{6i}$$

$$k_{C.F.} = M_{C.F.}/\beta_\delta = \omega^2 \cos^2 \delta_3 I_0 \tag{6j}$$

$$k = k_{A.L.} + k_{C.F.} = \omega^2[0.25a(\rho/2)C \cos^2 \delta_3 \tan \delta_3 R^4 + \cos^2 \delta_3 I_0] \tag{6k}$$

Hence, the ratio of natural flapping frequency to rotor r.p.m. is

$$F_F/N = \sqrt{1 + 0.75a(\rho/2)C \tan \delta_3 R^2/m} \tag{6l}$$

Eq. (6l) is plotted in Fig. 5, for $a = 5.85$; $C = 1$ ft.; $R = 20$ ft.; and $m = 2$ slugs.

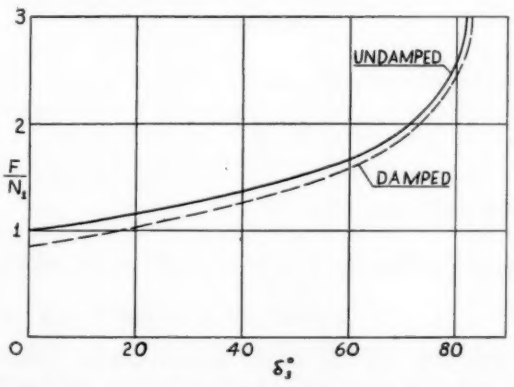

FIG. 5. Change is natural and damped flapping frequency ratios with changes in the cocked angle of the horizontal hinge. (See Fig. 4.)

(b) *Effect of Damping*

The differential equation of damped free flapping motion is $I_\delta\ddot{\beta}_\delta + c\dot{\beta}_\delta + k\beta_\delta = 0$. This equation, when solved, yields, as the standard, damped, frequency formula,

$$F_D = \sqrt{(k/I_\delta) - (c/2I_\delta)^2} \tag{7}$$

The damping term c may be evaluated as follows: Referring again to Fig. 4,

$\tan \Delta\alpha = r\dot{\beta}_\delta \cos \delta_3/\omega r = \Delta\alpha$; $C_L = a\,\Delta\alpha = a\dot{\beta}_\delta \cos \delta_3/\omega$

$$M = (\rho/2)aC\omega\dot{\beta}_\delta \cos^2 \delta_3 \int_0^R r^3 dr \tag{7a}$$

$$M = (\rho/8)aC\omega R^4 \dot{\beta}_\delta \cos^2 \delta_3 \tag{7b}$$

$$c = M/\dot{\beta}_\delta = (\rho/8)aC\omega R^4 \cos^2 \delta_3 \tag{7c}$$

Substituting terms of Eqs. (6k) and (7c) into Eq. (7)

$$F_D/N = \sqrt{1 + [0.75a(\rho/2)CR^2 \tan \delta_3/m] - [3a(\rho/2)CR^2/8m]^2} \tag{7d}$$

Eq. (7d) is plotted in Fig. 5 for the same conditions as were used in Eq. (6l) above.

Critical Damping

The critical damping is derived by equating Eq. (7) to zero and solving for c. Thus,

$$c_c = 2\sqrt{kI_\delta} = 2I_\delta\omega_n \tag{8a}$$

For the blade previously discussed, the ratio of actual damping to critical damping is:

$$c/c_c = 0.522/\sqrt{1 + 1.045 \tan \delta_3} \tag{8b}$$

Eq. (8b) is plotted in Fig. 6.

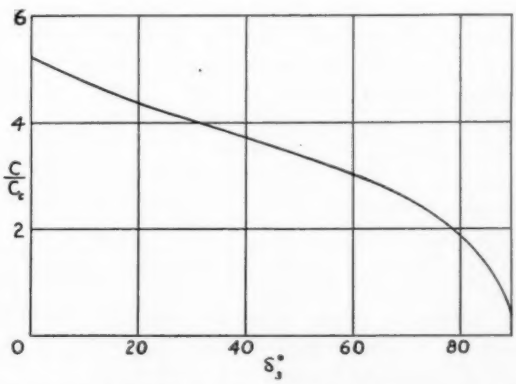

FIG. 6. Change in relative damping with changes in the cocked angle of the horizontal hinge. (See Fig. 4.)

Phase Angle

There is a very interesting and practical use for knowledge of the amount of damping present. When considering damped forced vibrations, the amount of damping has a great effect upon the phase angle between force and displacement, except when the forced frequency is equal to the natural frequency.

The following analysis does not take into account the lag in the lift force of the blade due to rapidly changing angle of attack. This will cause a further, though relatively small, phase shift in addition to that derived on the basis of the foregoing analysis.

Fig. 7 shows the phase angle between force and displacement, plotted against the ratio of forced frequency to natural frequency for several values of damping.[2] Assume it is found, either by experiment

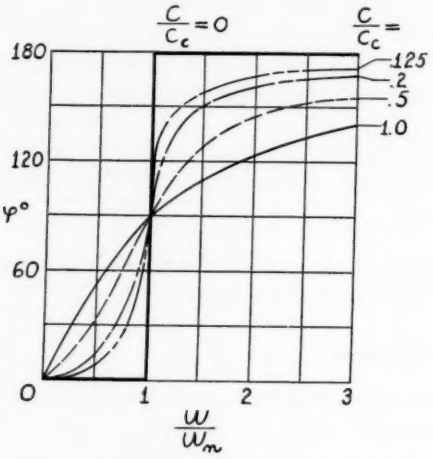

FIG. 7. Change in phase angle between disturbing force and displacement of oscillating body for changes in frequency ratios and relative damping.

or by calculation, that the value of maximum flapping for the blade discussed above occurs at an azimuth position of 230° when $\delta_3 = 0$. For the above example, $\omega/\omega_n = N/F_D = 1.175$ and, from Fig. 6, c/c_c is approximately 0.5.

From Fig. 7 the phase angle between maximum moment and maximum flapping displacement will be 107°. Thus, the maximum moment tending to cause upward flapping occurs at 230° − 107° = 123° azimuth position, measured from down wind.

Now, suppose it is desirable to have the maximum flapping occur when the blade is directly forward, at an azimuth position of 180°. To achieve this result, a phase angle of 180° − 123° = 57° is necessary.

From Fig. 7 it is found that for a phase angle of 57° $\omega/\omega_n = 0.75$, and Eq. (7d) can be solved for δ_3 using the numerical values from the example. However, since c/c_c is also dependent upon δ_3, successive trials must be employed for each new value of c/c_c.

Three trials yield $\delta_3 = 30°$, approximately, as the correct cocked angle of the horizontal hinge, such that the maximum flapping of the blade will occur directly forward.

NATURAL BENDING FREQUENCY

The blade has a natural vibratory frequency, due to internal flexibility, in the planes of flapping and rotation. The analysis which follows is based upon bending in the plane of flapping, but the same expressions may be utilized for bending in the plane of rotation.

The calculation of this natural frequency is perhaps best attacked by means of Rayleigh's energy method. Briefly, this method consists of equating the maximum potential energy in the blade, when the blade is at its greatest deformation, to its maximum kinetic energy when the blade is in its undeformed position, and solving for the natural frequency.

The details of the process are as follows: A shape is assumed for the first normal elastic curve. From this assumed curve, the maximum potential energy of the deflected blade is calculated by means of the equation

$$E_{Pot.} = (EI/2)\int_0^R (d^2y/dr^2)^2 dr \qquad (9a)$$

The maximum kinetic energy is calculated by means of the equation

$$E_{Kin.} = U\Omega_1^2/2\int_0^R y^2 dr \qquad (9b)$$

where Ω_1 is the natural frequency of the blade due to bending stiffness alone. For a blade held by a free pivot at one end, as shown in Fig. 8, it is assumed that

$$y = y_0[\sin \pi r/R - 3r/\pi R] \qquad (9c)$$

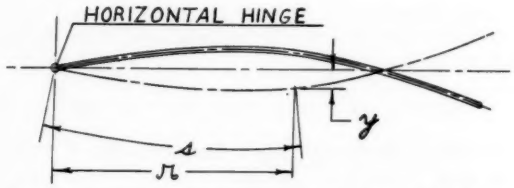

FIG. 8. Assumed elastic curve for blade bending in plane of flapping.

Substituting into Eq. (9a)

$$E_{Pot.} = (EI/2)(\pi^4 y_0^2/R^4)\int_0^R \sin^2(\pi r/R)dr = EI\pi^4 y_0^2/4R^3 \qquad (9d)$$

Substituting into Eq. (9b)

$$E_{Kin.} = (U\Omega_1^2 y_0^2/2)\int_0^R [(\sin^2 \pi r/R) - (6r/\pi R) + (9/\pi^2 R^2)]dr = 0.098U\Omega_1^2 y_0^2 R \qquad (9e)$$

Eqs. (9d) and (9e) are for uniform blades. When a blade has varying mass distribution and varying EI, these terms must be expressed as functions of the variable r, and taken under the integral sign.

Equating Eqs. (9d) and (9e) and solving for natural frequency,

$$\Omega_1 = (15.75/R^2)\sqrt{EI/U} \text{ radians per second} \quad (9f)$$

Effect of Centrifugal Force on Bending Frequency

If the vibration takes place when the rotor is turning, the maximum potential energy is increased over the maximum potential energy when the blade is not rotating. The increase in potential energy may be considered as arising from the fact that each particle of the blade moves against its centrifugal force when the blade deflects.

The rigorous method of calculating the frequency when the blade is under the influence of centrifugal force would be to revise the assumed elastic curve so as to satisfy the different conditions. However, the formulation of the elastic curve would be unduly difficult, and the resulting accuracy unnecessary.

Referring to Fig. 8, $s - r$ = the distance a particle moves against its own centrifugal force when the blade moves from neutral position to its maximum displaced position.

$$ds \approx dr[1 + (1/2)(dy/dr)^2] \quad (10a)$$

$$ds - dr = (1/2)(dy/dr)^2 dr$$

$$(dy/dr)^2 = (y_0/R)^2(\pi^2 \cos^2 \pi r/R - 6 \cos \pi r/R + 9/\pi^2) \quad (10b)$$

$$s - r = (y_0^2/2R^2)\int_0^r [(\pi^2 \cos^2 \pi r/R) - (6 \cos \pi r/R) + 9/\pi^2]dr$$

Performing the indicated integration,

$$s - r = (y_0^2/2R^2)[5.847r + (0.785R \sin 2\pi r/R) - 1.908R \sin \pi r/R] \quad (10c)$$

The potential energy of the entire blade due to the centrifugal force is

$$E_{Pot.\ (C.F.)} = \int_0^R (s - r)C.F._r dr \quad (10d)$$

where $C.F._r$ = centrifugal force of particle at r. Substitution for $(s - r)$ and $C.F._r$ in Eq. (10d) yields

$$E_{Pot.\ (C.F.)} = (\omega^2 y_0^2 U/2R^2)\int_0^R [5.847r^2 + (0.785Rr \sin 2\pi r/R) - 1.908Rr \sin \pi r/R]dr$$

Performing the indicated integration and evaluating,

$$E_{Pot.\ (C.F.)} = 0.608\omega^2 y_0^2 m \quad (10e)$$

Eq. (10e) is for a blade having a constant mass distribution. For a blade having varying distribution, U must be expressed as a function of r, and taken under the integral sign.

The most convenient method of combining the effects of the potential energies on the natural frequency is to ascertain the natural frequencies considering the energies separately, and then combine the frequencies in accordance with Eq. (2).

Eq. (9e) may be used to evaluate the maximum kinetic energy by using a different subscript for the natural frequency term. Equating the energy expressions and solving for the natural frequency gives $\Omega_2 = 2.49\omega$ = natural frequency due to centrifugal force alone.

The ratio between the frequency when the rotor is turning, and when it is at rest is

$$\Omega/\Omega_1 = \sqrt{1 + \Omega_2^2/\Omega_1^2} = \sqrt{1 + 6.2\omega^2/\Omega_1^2} \quad (10f)$$

where Ω is the natural frequency due to the combined effect of internal stiffness and centrifugal force. Fig. 9 is a plot of Eq. (10f).

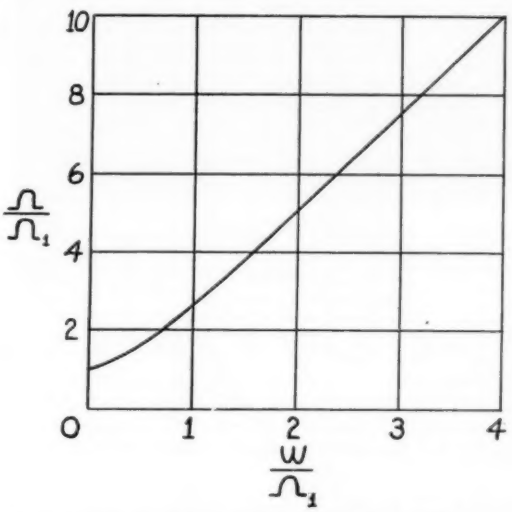

Fig. 9. Curve showing increase in natural bending frequency of blade due to rotor speed (ω).

Resonant Conditions

An unpleasant, and at times dangerous, vibration has been experienced in various rotor aircraft while on the ground with the rotor turning. These disturbances have all been identified as ground resonance. Until the present, there has been no comprehensive analysis which satisfactorily explains these phenomena.

Recently a series of high-speed motion pictures were taken of a turning rotor which was made to oscillate in ground resonance—the camera being held in a position about ten feet above the plane of the rotor. A study of the motion picture revealed that the rotor speed was 5/3 the frequency of the oscillation of the ship on its chassis. It was further noted that a blade was in a given position relative to a given point on the cyclic path of oscillation of the hub, thus indicating that resonance could occur in a rotor when the denominator

of the fractional ratio of rotor speed to oscillation of the ship is divisible by the number of blades. In addition, it was noted the direction of sway of the ship in relation to its longitudinal axis remained the same. It was assumed that the frequency of the ship on its chassis could be varied from a relatively low value laterally to a relatively high value longitudinally depending upon the inertia distribution and chassis arrangement in combination with azimuth axis of the oscillation. With a knowledge of the above phenomena a group of suitable mathematical expressions was found, one of which would satisfy the condition explored with the slow motion moving picture.

Fig. 10 shows a graph on which the ratio of rotor speed N to the frequency of the blade about the vertical hinge F_B is plotted as abscissa and the ratio of rotor speed N to the frequency of the ship (either on the ground or in the air) F_S is plotted as ordinate. Curve

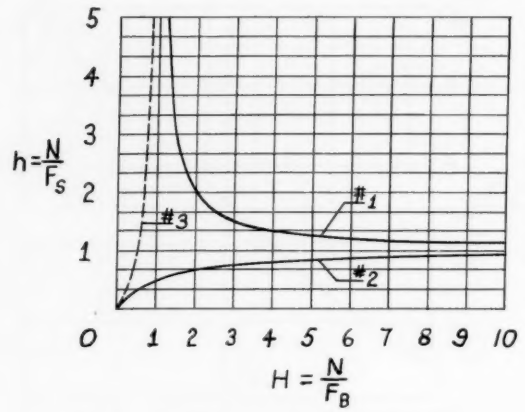

FIG. 10. Ground resonance prediction chart.

1 was checked at one point by the data obtained in the slow motion motion picture as outlined above. Curve 2 represents the case where all of the blades are simultaneously deflected in the same direction as, for instance, by a one wheel landing. Although mathematically present, no empirical check has been made for curve 3 which probably has very little significance in hinged blades since the frequency F_B is never likely to be greater than rotor speed when the rotor is turning at high speed. The value of the blade frequency ratio H may be readily determined, but the value of the ship frequency ratio h will depend upon the relative fore and aft and lateral inertia of the ship for the air condition and upon the combination of the component inertias and spring characteristics of the chassis when the machine is on the ground. Because the ship frequency is relatively low when the machine is air-borne, the value of h is likely to be great and when combined with values of H as found on existing machines, resonance of this character while air-borne is very unlikely if not impossible. When a soft, large deflection, landing gear is used the intersection with curves 1 and 2 occurs at a low rotor speed where the resonant forces are ineffectual in creating serious disturbances. When the value of h is relatively low, it is necessary to have ample damping characteristics in the blade dampers and shock struts to prevent ground resonance.

CONCLUSIONS

(1) With normal vertical pin locations, and without additional centering springs, the natural pendular frequency of the blade about the vertical pin is from $^1/_3$ to $^1/_5$ the rotor speed. The theoretical value of frequency is usually reduced because of the lack of fixity of the hub. This reduction in pendular frequency of the blade amounted to 30 per cent in one case.

(2) With additional specialized centering means, the natural pendular frequency of rotor blades may be made to vary with amplitude of oscillation.

(3) The natural flapping frequency of a rotor blade with the flapping axis perpendicular to the blade, and located on the axis of rotation, neglecting damping is equal to the rotor r.p.m.

(a) Moving the flapping axis outboard increases that natural frequency in a normal design approximately $2^1/_2$ per cent.

(b) Average coning of the blade reduces the basic natural frequency in a normal design approximately three per cent.

(c) Damping reduces the basic natural frequency approximately 15 per cent with the flapping axis perpendicular to the blade.

(d) Cocking the horizontal hinge toward the leading edge of the blade has the effect of increasing the value of the damped natural frequency with increases in the angle of cocking.

(4) The natural bending frequency in the plane of flapping depends so much upon the structure of the blade that no one value can be given for this term. The natural bending frequency in the plane of flapping for a plywood covered blade having a chord of 1 ft., a radius of 20 ft. and a 17 per cent thickness ratio, at 200 r.p.m. of the rotor, is approximately $2^3/_4$ times the rotor speed.

(5) A more complete analysis of all of the possible combinations of resonance should be done; however, it is believed that the mathematical and empirical analysis herein will assist those interested in rotor aircraft design to eliminate resonance problems.

REFERENCES

[1] Den Hartog, J. P., *Mechanical Vibrations*, pages 352–353, McGraw-Hill Book Company, New York, 1934.

[2] *Loc. cit.*, page 58.

Institute Notes

Technical Sessions at the Ninth Annual Meeting of the Institute

The Ninth Annual Meeting of the Institute will be held at Columbia University on January 29, 30, 31, 1941. There will be three days of technical sessions devoted to Aerodynamics, Airplane Design, Air Transport, Meteorology, Power Plants, Radio and Instruments, Structures, and other subjects. Sponsors for the various sessions are being appointed and a complete list will be published as soon as it is available. Anyone who wishes to present a paper may send to the Institute an extended abstract or the complete paper for consideration relative to its suitability for presentation at the meeting. These will be forwarded to the sponsors of the respective sessions.

Shell Intercollegiate Aviation Scholarships to Be Awarded This Month

The 49 college pilots selected as the most outstanding pilots developed in the Civil Aeronautics Board's pilot training program competed in the semi-finals of the Shell Intercollegiate Aviation Scholarships early this month to determine the seven pilots who will fly at Bolling Field, Washington, D. C., August 15th for the three scholarship awards of $1000, $750, and $500.

One hundred and sixty colleges and universities in 41 states are competing in the contest, which is sponsored by the Institute on a grant from the Shell Oil Company.

The awards will be made the day after the flights at a luncheon at the Hotel Mayflower, Washington, D. C., at which Major James H. Doolittle, President of the Institute, will preside. The winners of the scholarships and other awards will be announced in the September issue of the Journal.

Personnel Opportunities

The Personnel Bureau serves individual members, as well as organizations seeking to employ aeronautical specialists. Any member or organization may have requirements listed without charge.

Wanted

Experienced aircraft draftsman capable of handling powerplant projects through layout detailing and shop fabrication. Must be thoroughly familiar with aircraft materials and methods and have general knowledge of structures, mechanics, and aerodynamics appertaining to powerplant installations. Inquiries from personnel employed by other aircraft manufacturers engaged in national defense production not desired. Address reply to Box 103, Institute of the Aeronautical Sciences.

Aircraft Inspectors: Must have wide experience in the manufacture of all-metal aircraft. Final assembly and ground test inspectors must have experience with installation of latest model airplane engines. Address reply to Box 104, Institute of the Aeronautical Sciences.

Student Branches

University of Washington. At the last regular meeting of the Student Branch on May 18th, the following officers were elected: Victor Ganzer, Chairman; Robert LeBeck, Vice-Chairman; William Hamilton, Secretary-Treasurer.

Luncheon in Honor of Paul Kollsman and F. W. Magin

On July 18th a luncheon was held at the Rainbow Room at the RCA Building in honor of Paul Kollsman and F. W. Magin, President of the Square D Company, the donors of the $50,000 gift to establish the Paul Kollsman Library.

The luncheon was attended by more than sixty leaders in aviation. Major Lester D. Gardner presided and received from Mr. Kollsman and Mr. Magin checks totaling $25,000 for the establishment of the library. Short talks praising the generosity

Mr. F. W. Magin, President of the Square D Company (left) and Mr. Paul Kollsman (right) presenting Major Gardner with checks for $25,000 to start the Paul Kollsman Library.

and foresightedness of Mr. Kollsman and Mr. Magin in making the fund available were given by Dr. Harrison W. Craver, Librarian, Engineering Societies Library; Gill Robb Wilson, President, National Aeronautic Association; and Col. John H. Jouett, President, Aeronautical Chamber of Commerce of America.

With the checks, Mr. Kollsman and Mr. Magin handed Major Gardner the following letter.

"The plan to establish a library for lending aeronautical books to members of the Institute of Aeronautical Sciences and other persons interested in aeronautics, as suggested by you and others has received my careful consideration. I have also consulted with my associates in the Square D Company, and we agree that by making books available on loan, a valuable service will be rendered to aeronautical engineers, pilots, Army and Navy officers and others who wish to keep themselves informed regarding the rapid advances being made in the science and art of aeronautics.

"So that the plan may be effective at once on a basis which will be sufficiently broad to render effective service, I and the Square D Company of Detroit send you herewith our checks aggregating $25,000.00 to endow such a library. We further agree to provide an additional $25,000.00 by each of us making a contribution of $12,500.00 during the next five years to enlarge and maintain this library.

"In accordance with the plan suggested, such endowment will be kept as a separate fund and will be used as authorized by a committee to be appointed by the Council of the Institute. In case the library shall have become self-supporting and all of the gift of $50,000.00 has not been expended after five years from this date, we authorize the Institute of the Aeronautical Sciences to invest any sum remaining in the fund in United States Government securities or savings banks and to use the income for the purchase of books to increase the usefulness of the library.

"We shall be glad at all times to assist the work of the library with such advice and suggestions as may be requested, but we wish to make it clear that this gift is an outright contribution to the Institute of the Aeronautical Sciences, Inc., is irrevocable and under the complete direction of the Council of the Institute.

"In establishing this endowment, we hope that the plan will not only provide books and magazines for lending purposes, but that there will also be started an information service and a bulletin which will keep the aeronautical profession informed as to the progress being made in the aeronautical sciences, both in this country and abroad. In this way the maximum usefulness of this endowment will be assured."

Council Approves Establishment of Paul Kollsman Library

At a meeting on July 25th, the Council unanimously approved the establishment of the Paul Kollsman Library and appointed a committee, composed of Paul Kollsman, Charles H. Colvin, Allan D. Emil, F. W. Magin, and Lester D. Gardner, to supervise the activities of the library and authorize the budget and procedure for its operation.

The members of the Council expressed the appreciation of the Institute by passing the following resolutions:

WHEREAS, Paul Kollsman of Greenwich, Connecticut, and the Square D Company of Detroit, Michigan, through its President, F. W. Magin, have given $25,000 to the Institute of the Aeronautical Sciences and have agreed to give an additional $25,000 during the next five years for the establishment of an aeronautical library from which books may be borrowed,

Therefore, Be It Resolved, on behalf of the members of the Institute, that the Officers and Council do hereby express to Mr. Kollsman and the Square D Company, through Mr. Magin, appreciation for the most generous gift which they have made for such a worthy and practical purpose;

And Be It Further Resolved, that the lending library be known as The Paul Kollsman Library; that the funds for this Library be kept separate from the general income of the Institute and that expenditures from the funds of the Library be made only on the authorization of a committee appointed by the Council to have such power;

And Be It Further Resolved, that the Council expresses its endorsement of the plans and purposes of the Library and the monthly bulletin to be published by the Library and records its belief that they will render to American aeronautics a great service at a time when they may have a most helpful influence on national defense.

In recognition of Mr. Charles H. Colvin's efforts toward the establishment of the library, the following resolution was passed:

Resolved, that the Officers and Council of the Institute of the Aeronautical Sciences do hereby express to Charles H. Colvin their thanks and appreciation for his effort in connection with the gift of Paul Kollsman and the Square D Company to the Institute.

I.Ae.S. Student Branch Awards

Recipients of the Student Branch Scholastic Award and the Student Branch Lecture Award, in addition to those listed in the June and July issues of the Journal, are given below.

Student Branch Scholastic Award: George Hayes, University of California; Allen E. Puckett, Harvard University; Walter G. Vincenti, Stanford University; Alex J. McCulloch, Tri-State College; B. J. Hall, Notre Dame University; Walter Elvin Mason, Virginia Polytechnic Institute; William Henry P. Drummond, University of Washington.

Student Branch Lecture Award: Milton A. Miner, Stanford University; Sidney Hammarlund, Tri-State College; E. A. Pratt, Notre Dame University; Harry Christie Archer, Virginia Polytechnic Institute; Antoni John Sobieralski, University of Washington.

Changes in Membership

The following changes in the membership of the Institute have occurred since the publication of the previous issue of the Journal.

Elected to MEMBER Grade

Bergen, William Benjamin, B.S. in Ae.E.; M.I.Ae.S.; Vibration Engineer, Glenn L. Martin Co.

Dickinson, Warren T., S.B. in Ae.E.; M.I.Ae.S.; Flight Research Engineer, Douglas Aircraft Co.

Donovan, Robert Charles, M.I.Ae.S.; Designer, El Segundo Div., Douglas Aircraft Co.

Gorrell, Edgar Staley, D.Sc.; M.I.Ae.S.; Col., U. S. A.; President, Air Transport Association of America. (See W.W. in A.)

Gregory, Alfred Thorne, Dr.Ing.; M.I.Ae.S.; Chief Engineer, Ranger Aircraft Engines, Fairchild Airplane and Engine Corp.

Hutchinson, Lester Bowser, A.B. in M.E.; M.I.Ae.S.; Engineer, Brewster Aeronautical Corp.

Knoll, Denys William, S.M. in Meteorology; M.I.Ae.S.; Lieut. (Aerological), U. S. Navy.

Larsen, Victor A., M.I.Ae.S.; Vice Pres. and Chief Engineer, Spencer-Larsen Aircraft Corp.

Moss, Virgil Donald, B.S.; M.I.Ae.S.; Stress Engineer, Glenn L. Martin Co.

Orshansky, Elias, Jr., M.I.Ae.S.; Vice Pres. in Charge of Engineering, The Acrotorque Co.

Percival, Edgar Wikner, M.I.Ae.S.; F.R.Ae.S.; Founder and Director, Percival Aircraft Ltd., England. (See W.W. in B.A.)

Rice, Janvier Mayhew, E.E.; M.I.Ae.S.; Executive Engineer, St. Louis Airplane Div., Curtiss-Wright Corp.

Uihlein, Alfred, M.D.; M.I.Ae.S.; Surgical Fellow, Dept. of Aviation Medicine, Mayo Foundation for Medical Education and Research.

Wheaton, Elmer Paul, B.S.; M.I.Ae.S.; Sound and Vibration Engineer, Douglas Aircraft Co.

Elected to Industrial Member Grade

Malkovsky, Louis, M.I.Ae.S.; Factory Manager, Sperry Gyroscope Co.

Smith, John Story, M.I.Ae.S.; Pres., Jacobs Aircraft Engine Co.

Sweeney, Beauregard, M.I.Ae.S.; Pres., Cox & Stevens Aircraft Corp.

Elected to Technical Member Grade

Brice, Philip Edgar Rowland, B.S. in Ae.E.; Engineer, Republic Aviation Corp.

Harin, Hongskula, A.R.Ae.S.; Flying Officer, Royal Thai Air Force. Thailand (Siam).

Hartley, Max Elmo, Engineer, Boeing Aircraft Co.

Kohr, Bradley George, B.S. in Ae.E.; Chief Engineer, Boston-Maine Airways, Inc.

Mitchell, Albert Edgar, Aeronautical Engineer, Frederick J. Knack Engineering Co. (See A.A.D.)

Olsson, Thomas, Draftsman, Harlow Aircraft Co.

Sandel, William DeRay, Jr., Methods Engineer, Bendix Aviation Corp.

Schram, Richard Arney, Layout Draftsman, Bendix Products Div., Bendix Aviation Corp.

Aeronautical Reviews

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps

Aerodynamics

Determination of the Interference Factors of the Wind Tunnel with Partially Enclosed Jet. R. Giovannozi. Theory previously developed by the author is applied to the calculation of the interference factors of the wind tunnel with partially enclosed circular walls of the two following types: circular cross-section with two rigid boundaries and two free boundaries both of equal area, whereby the rigid boundaries are bisected by the axis Y and the free boundaries by the axis X; and partially enclosed circular walls with two rigid boundaries and two free boundaries, both of equal area, whereby the rigid boundaries are bisected by the axis X and the free boundaries by the axis Y. The above theory is treated as a problem of a partially enclosed jet in which the rigid boundaries are represented by the real part of a function of complex variables while the free boundaries are represented by the imaginary part of the function, or *vice versa*. The calculation is developed for the elliptical distribution of lift. *L'Aerotecnica*, May, 1940, pages 398–411, 2 illus., 66 equations.

Aircraft Design

The Design of Airplane Seating. W. McArthur. Difficulties in designing airplane seats are chiefly structural for most seats are cantilevers. Loads on pilots' seats, required by the Air Corps, and design loads and movements of an adjustable seat for pilots are illustrated in drawings. The design of seats for pilots, passengers, and radio operators is considered. System for calculating for the tubing required in these bent-tube seats, and termed "perspective geometry," is discussed, and the procedures in design, mockup and tests are outlined. *Aero Digest*, June, 1940, pages 79–80, 92, 95, 7 illus.

The Heinkel Technique from the Patents of the Designer. Arrangement for damping the oscillations of a control surface (French patent No. 838,618, results of tests being given in the D.V.L. Jahrbuch, 1938, pages 1–249). A light alloy hardening at room temperature and giving a delay of working, after hardening, of one to six days (French patent No. 839,906). Fowler flap serving an aileron (French patent No. 844,674). Pilot's chair designed for improving views to the rear and the front (French patent No. 827,556). Descriptions of these patents. *L'Aéronautique*, April, 1940, pages 137–138, 6 illus.

Italian Solutions to the Problem of High Speeds from the Examination of the Macchi-Castoldi M.C.72 Racing Seaplane. P. Léglise. The increase of speeds from 350 km./hr. to 600 and even 700 km./hr. brings forth a new series of technical problems, such as those taken up by M. Castoldi in his paper, "Italian Aircraft of High Speed," parts of which are included by the author in his discussion. It is shown how solutions for the following were obtained in the design of the M.C.72: incorporation of maximum power in a fuselage of minimum dimensions; engine system and unusual elements of strength and connections; simple or complex cooling of the engines producing 2500 to 3000 hp.; elimination of the tilting moment and indispensable reduction of the propeller diameter, particularly by use of coaxial propellers. Characteristics of the Macchi high-speed seaplanes (1926–1931) are given in a table and discussed, and the design of the M.C.72, which attained 709.209 km./hr. over a 3-km. course in 1934, is analyzed in great detail. Fuselage, surface radiators, circulation of gasoline, oil, and water, and coaxial propellers are considered.

Drawings include: structure of the engine mount for the Fiat AS.6 3000-hp. engine in the M.C.72; maximum cross-sections of the Macchi M.39, M.52, M.67, and M.C.72; views of profile, side and planform, and of successive cross-sections of the fuselages of the Macchi M.39, M.52, M.67, and M.C.72; and diagrams of the circulation of fuel, oil, and water in the M.C.72. Table gives the thrust of two propellers arranged coaxially and counter-rotating, compared with the thrust of these same propellers operating separately as pushers and tractors. Two photographs show the Pegna P.7 racing seaplane with two hydrodynamic vanes for assistance in taking off from the water, propulsion during the course in the water being furnished by a marine propeller, and control by a marine rudder. *L'Aéronautique*, April, 1940, pages 127–136, 13 illus., 1 table, equations.

Rudder Control Problems on Four-Engined Airplanes. C. L. Johnson, Lockheed Aircraft Corp. Paper presented at the Annual Meeting and previously abstracted from preprint (see page 261, April issue of the Journal). *S.A.E. Jour.* (*Trans.*), June, 1940, pages 262–270, 21 illus., 2 tables.

Tomorrow's Light Plane Will Have These Features. W. B. Stout. Speeds of light airplanes will have to be stepped up to twice the speeds of today. Pusher propeller with its full propeller disc active in pushing, or twin propellers on the wings must be used because of the great mechanical detriments of a small propeller blowing against a big fuselage. Retractable landing gear and full cantilever wings are necessary to reduce drag and thus increase speed. Maximum vision must be provided as a means of safety. Radio apparatus will be needed. Simpler flying instruments and controls must be developed, and adjustable-pitch metal propellers are recommended. *Aviation*, June, 1940, pages 36–37, 110, 4 illus.

Engineering Experimental Airplanes. W. A. Hite. Engineering management in regard to rapid development work necessary, shop engineering, handling experimental drawings, and scheduling the work is described. Principal features of the Vultee Trainer airplane, now under contract to the U.S. Army Air Corps, are presented to illustrate what is meant by "designing experimental airplanes for manufacturing economy." Wing, control surfaces, and fuselage of the Trainer are discussed. S.A.E. paper for National Aircraft Production Meeting, October, 1939. *Aircraft Engg.*, May, 1940, pages 153–156, 13 illus.

Stalls and Spins Must Go! T. Hardin. Most recent spin problem faced by engineers has developed with the design and use of highly tapered wings. Dangerous stall characteristics introduced by this design, and use of slots and warping of the wing to counteract conditions responsible for this type of stall are mentioned. Development of spin-proof, stall-safe airplanes, which has not been as rapid as conditions appear to warrant, is urged. Civil Air Regulations prescribing desired spin characteristics are discussed. A few types of spin and stall accidents which might have been avoided if the airplane had been inherently safer are considered. *Popular Aviation*, July, 1940, pages 14–15, 66, 68, 4 illus.

The Utilization of Thin Profiles. An arrangement designed to increase the possibilities of using thin profiles on the wings of modern airplanes has been patented by the D.V.L. In order to reduce the aerodynamic drag of the wings, it is proposed not only to reduce the lifting surface but also to adopt thin profiles having tapered edges and on which the position of the point of maximum thickness is located decidedly far back. These profiles give only a low maximum lift and greatly reduce the effectiveness of the flaps. At landing, for example, there is produced, at large incidences, all along the leading edge of the tapered wings, the breaking away of the airflow which cancels the action of the arrangements for increasing lift placed in the rear of the wings.

Also in order to increase the maximum lift of the surfaces at the opportune moment, as well as to profit by a gain in fineness of the wings with thin profiles, the D.V.L. engineers decided to give to the leading edge an artificial contour which disappears during the period of high-speed flight. This contour would be obtained, it seems, by a special intradorsal flap, which would be mounted elastically, without articulation, on the upper face of the profile. This flap appears to be a close relative to the Handley Page front slot; the Germans anticipate that the effect of the slot which it would produce could be judiciously directed and calculated evidently in order to suppress the diversions of flow. It seems, on the other hand, that the variation of the contour of the nose of the profile could be obtained by a pneumatic arrangement of a principle similar to that of the Goodrich deicers. Brief note. *Les Ailes*, April 25, 1940, page 9.

Rotary-Wing Aircraft

Rotary-Wing Aircraft. J. A. J. Bennett. Flapping motion of the rotor blade is aerodynamically damped by the resulting changes in lift, but, both the damping and restoring moments being periodic, it has been suggested by Glauert and Shone that in a steep dive the motion might become unstable. It is shown that stability extends well beyond the practical range of conditions in which the rotor may be required to operate. In spite of the serious dynamical problems presented by flapping, nearly all rotary-wing aircraft use flapping rather than feathering hinges, one great advantage of the former being the freedom from heavy bending moments in the vertical plane at the blade root. A modification which attempts to combine certain advantages of each system is effected either by tilting the flapping hinge axis so that it is inclined to the radial axis of the blade, or by mechanically associating a feathering displacement with a displacement about the flapping hinge.

Calculations and discussions cover: disturbed flapping; flapping stability in a dive; effect of simplification of the general equation; an extreme case of disturbed blade motion; rotor vibration; harmonic analysis; periodic coning; and results of vibration tests made at different air speeds with two-bladed and three-bladed rotors, and recorded by two synchronized R.A.E. Type B vibrographs located at different positions on the aircraft. Continued. *Aircraft Engg.*, May, 1940, pages 139–141, 146, 9 illus., 1 table, 19 equations.

Stress Analysis and Structures

Channel Section Constants. Graph shows constants for channel sections. Value of ratio $b/a = 4$ (where b equals the width and a the height) is the usual practical limit owing to the instability of the gauges in general use. *Aircraft Engg.*, May, 1940, Supplementary detached sheet No. S 2a.

Forming Aircraft Structural Components. Procedure is described for forming an extruded Tee section $2 \times 2 \times 1/4$ in. of an aluminum alloy N.A. 26S (produced by the Northern Aluminium Company to meet DTD.364) which was required to be bent into an airfoil profile for use as a wing member of a large aircraft. Composition and properties of N.A. 26S and this example of recommended British procedure are presented in a short note. *Metal Industry*, June 7, 1940, page 506, 1 table.

A Low Density Material for Aircraft Structures. V. E. Clark. Duramold, a material developed for aircraft structures, has a specific gravity which may be accurately controlled within ± 3 per cent, within a range from 0.5 to 0.9. Within this range, the strength and elastic modulus vary, roughly, as the density. In its final form this material is sufficiently non-hygroscopic and free from attack by fungi or molds and other kinds of deterioration to answer all practical requirements of airplane service operation. Specimens having a ratio of edge area to total area thousands of times as great as that existing in airplane shells, show an increase in weight of less than one per cent after seven weeks of complete immersion, with negligible change in dimension, no deformation, and no change in physical characteristics.

Important physical characteristics of Duramold in four of its many forms are shown. In resistance to fatigue, based on allowable stress, for equal weight per unit area, Duramold is about 50 per cent better than 17ST duralumin. There is no creep. S.A.E. paper for World Automotive Engineering Congress, 1939. *Royal Aeronautical Soc., Jour.*, May, 1940, pages 433–438, 3 illus., 1 table.

Solid Organic Materials. N. A. de Bruyne. Characteristics of a new class of materials for use in engineering are considered with references to those suitable for aircraft structures. Monomers and polymers, primary and secondary bonds, and means for comparing tensile and compressive strength properties of organic and metallic materials are explained. A general rule is laid down as follows: for a strut of given weight and length, the failing load will increase as the material is "expanded" as long as Young's modulus and proof stress do not fall off much more rapidly than the decrease in density. Failure by Euler instability and failure of a flat sheet by wrinkling are discussed.

Tables compare the following: tensile strength, specific gravity, and the strength-specific gravity ratio of steel, duralumin, Elektron, spruce, flax, cotton, Sisal, unreinforced P.F. resin and silk; proof stress, specific gravity and strength-specific gravity ratio of steel, duralumin, Elektron, spruce, and balsa; proof stress, Young's modulus, density, load-density ratio, and modulus-density ratio (E/ρ) for steel, duralumin and Elektron; and modulus, density, E/ρ, E/ρ^2, and E/ρ for steel, duralumin, Elektron, Nignostone (compressed beechwood), spruce, balsa, and rubber. The ratios E/ρ^2 and E/ρ^3 given in the last table indicate the figure of merit for failure of a strut and failure of a flat sheet by wrinkling. To be continued. *Aircraft Engg.*, May, 1940, pages 137–138, 1 illus., 4 tables.

A Theoretical Investigation of Plastic Torsion in an I-Beam. D. G. Christopherson, Oxford University, England. Distribution of stress in an I-beam in torsion is investigated by a method of successive approximation, and the regions of initial yielding are determined for several values of the angle of twist. Formulas are given for elaborating the methods of Southwell, and of Shortley and Weller in order to facilitate this determination. The value of the stress-concentration factor in the fillets is found to agree well with results obtained by soap-film tests, and regions of plastic flow approximate closely those observed by MacGregor and Hrones by the use of the etching method.

Paper was planned with a view to comparing this theoretical approach to the problem of plasticity with the experimental approach recently presented by MacGregor and Hrones. However, it has been found desirable to make use of certain formulas not contained in the earlier paper, which, it is believed, increase the accuracy obtainable by the use of a mesh of given size, and which thus accelerate the convergence. A.S.M.E. paper. *Royal Aeronautical Soc., Jour.*, May, 1940, pages 425–432, 7 illus., 7 equations.

Elastic Stability of the Cylinder with a Thin Wall. P. Cicala. For a sheet having as a surface part of a cylinder of generic section, the fundamental equations are found for the study of the stability of elastic equilibrium. For the circular cylinder the equation is deduced resulting in its more reduced expression, simplified on the basis of the single hypothesis of the thinness of the wall. The equation is applied to the determination of the critical load of a panel supported at the boundary and subject to compression in the direction of the generatrix. *L'Aerotecnica*, May, 1940, pages 357–373, 1 illus., 29 equations.

Plastic Planes. Bradley Jones. Comments on the Longren plastic fuselage of 1922, on other attempts at plastic airplanes, and on the present Clark F-46-A fuselage and Timm plastic airplane. The opinion is expressed "that the Clark and the Timm have performed well is, in itself, no guarantee that larger planes can be successfully built of plastic. There will be many problems to be solved in going to larger sizes." *U.S. Air Services*, June, 1940, pages 28, 30.

Aircraft Accessories

Recent Developments in the Use of Hydraulic Power. H. C. Town. Review of "all types of devices shows that hydraulic actuation constitutes the most reliable basis for control of retractable undercarriages, auto-pilots, gyroplanes, composite apparatus for mid-air launching, and shock-absorber struts." Under the part devoted to aircraft developments, the Siemens auto-pilots (with diagram of layout), Bendix aircraft control, and a gyroscopic course-director for aerial vehicles and torpedoes are briefly discussed.

Article also covers: use of hydraulic power in the plastic and metal stamping industry; application to automobile developments; hydraulic speed-control developments; ship's machinery; high-speed reciprocating hydraulic drives; hydraulic shaping machines; problem of feed irregularity through changes in pressure and viscosity; and application in the textile industry. *Inst. Mechanical Engrs., Jour. & Proc.*, May, 1940, pages 129–141, 12 illus.

Aircraft Maintenance

Maintenance in the Field. Series of photographs illustrate the work being done on aircraft of the British air forces in France to keep them airworthy. *Flight*, May 23, 1940, pages 474a–474d, 11 illus.

American Airlines Maintenance at LaGuardia Field. Photographs with brief explanations of devices used. *Aviation*, June, 1940, pages 56–57, 10 illus.

Aircraft Manufacture

Boxing for Export. H. J. Emerson. Designing of export cases that will protect the plane as well as cover it. *Aviation*, June, 1940, pages 40–41, 120, 128, 11 illus.

Forming Sheet Metal Aircraft Parts. R. B. Gray. New furnace developed by the Glenn L. Martin Company for melting zinc and zinc alloys for making drop-hammer dies, and the stretching press used in connection with the forming of curved sheets for cowling and other parts of the aircraft fuselage are described. From "Metal Progress." *Metal Industry*, June 14, 1940, page 517.

Machines for Sorting Rivets. Rivet-sorting machinery developed by the Tool Design Department of Glenn L. Martin Company to sort salvaged rivets, it is said, will lop around $12,500 off an annual dead loss of $15,500. Most of the sorters were sent on to more important work, and today the heterogeneous collection of rivets clatter down a track from a hopper, click into little slots on a wheel and drop off the perimeter into just the right box. Machine separates round-head from flat-head rivets at a high rate of speed, the rivets running along a track through which, at one point, the flat heads slip into a small bin while the round heads are carried on to another. Head-selector device works twice as fast as the length selector device. Description. *Aero Digest*, June, 1940, page 100, 3 illus.

Men and Machines. Descriptions of new machines for use in automotive production. *Automotive Industries*, June 15, 1940, pages 558–561, 589, 7 illus.

New Equipment. Kaufman Hi-Duty No. 5-A improved tapping machine with a No. 40 index and eight-station chucking style dial arranged to hold circular pieces for tapping. Farnham Duplicating milling machine designed especially for the production of aluminum-alloy wing spars. General Engineering GPR wide-range compression riveter designed to extend the use of squeezed rivets. Savage nibbler machines to which new and improved features have recently been added. New line of Steelweld bending presses which are adaptable for extensions of bed and ram at one or both ends. American Brass bench-type machine for attaching ferrules. Continuous milling of rods is made an automatic operation through the setup employing Detroit Universal Duplicator standard control unit with any standard vertical milling machine. Short descriptions or few details of these machines. *Aero Digest*, June, 1940, pages 138, 141–142, 145, 4 illus.

Production Line Private Planes. Alma Heflin. An innovation in the form of an overhead trolley is expected to step up production at least 15 per cent in the Piper Aircraft Corporation plant. With the 3000 ft. of monorail already installed and in operation approximately 50 fuselages can be carried along in production at a time. Description of operations in the plant and use of the overhead trolley. *Aero Digest*, June, 1940, pages 54–55, 7 illus.

Value Received from an Engineering Department. H. L. Hibbard, Lockheed Aircraft Corporation. Duties of the engineering manager and the chief project and chief research engineers at Lockheed Aircraft Corporation, personnel work carried out in the Engineering Department, and means taken to keep the 850 engineers informed of up-to-date developments are discussed. To be continued. *Aviation*, June, 1940, pages 44–45, 122, 124, 4 illus.

Welding Technique in Aircraft Construction. K. Krieger. Translation of a portion of the German Air Force light-metal structure handbook, "Flugzeug-Leichtmetallbau," supplementary to the extracts from the German Air Force welding handbook previously published. Oxyacetylene, gas, arc, seam, spot, butt and lap welding of the light alloys is considered, including some of the following in one or the other of the different welding methods; how the edges to be joined should be prepared; special precautions in welding magnesium alloys; preparation and preheating of the parts; flames for light metals; flux, jet, welding speed and direction; choice of electrodes; sheet thicknesses; welding qualities of light alloys; and soldering and brazing of light alloys. Examples of types of welded fittings commonly made from aluminum are illustrated. *Aircraft Engg.*, May, 1940, pages 157–158, 8 illus., 3 tables.

What's New in Machine Tool Design. F. J. Oliver. Cross-section of current design trends indicating that surprisingly few machines have been designed specifically for war work. Despite the fact that the machine-tool industry is constantly expanding its capacity to meet fresh demands, it has still found time to proceed with development of new ideas, although it was generally assumed last September that new designs would largely be shelved to get out production on standard models. Review is compiled from announcements received in the last two months. *Iron Age*, June 6, 1940, pages 59–64, 19 illus.

Skill to Order. M. H. Carrington. Apprenticeship program inaugurated at the Lockheed aircraft plant to insure a steady supply of craftsmen. *Popular Aviation*, July, 1940, pages 42–43, 56, 3 illus.

Aircraft Performance

Optimum Climb to Height. J. Corner. Quickest method of attaining height at a point distant horizontally from the base is calculated. Two distinct types of climb arising in aviation are pointed out. In the first it is necessary to climb to a given height without attaching any importance to horizontal distance covered. An example is a climb to take up patrol at a given height, and obviously the quickest way to do this is to climb at the maximum rate of climb possible at each instant. Second type of climb is more important, and in this it is necessary to climb to cruising height while, at the same time, traveling as far as possible in a certain horizontal direction. Examples are the initial climb of transport airplanes and bombers, and the "chasing" climb of a fighter which has taken off to pursue an enemy. A flatter climb than in the first type may have a horizontal speed sufficiently great to more than compensate for the extra time required to reach cruising height. A method is presented for calculating the second type of climb. This aspect of climbing to height, which does not seem to have been presented elsewhere, incidentally raises the point as to whether there is any difference between climbing as rapidly and climbing as economically as possible. *Aircraft Engg.*, May, 1940, pages 147–148, 1 illus,. many equations.

TESTING

Landing by the Yardstick. J. Farber. System devised by T. de Port at Wright Field for recording airplane landing and take-off performance is described. *Popular Aviation*, July, 1940, pages 44–46, 76, 5 illus.

Aircraft Patents

Trend of Invention. Title, owner, and number only of United States patents of interest to the aeronautical industry. *Aero Digest*, June, 1940, page 153, 6 illus.

Aircraft

New Airplanes. The Germans have studied the construction of their Messerschmitt pursuit entirely from wood. They have commented with interest and have raised again the old dispute in the aeronautical field between all-metal and all-wood construction, according to the Italian magazine, "Vie del' Aria." Difficulties of supplying light metal, as well as the possibility of assigning the construction of the airplane to factories not tooled for metal working have evidently led the Germans to consider this solution.

The same journal states that the Galtier V.G.-50 bomber, developed by the French Arsenal de l'Aeronautique, weighs 3400 kg. loaded. Its speed, with two Hispano-Suiza engines placed in tandem in front of and to the rear of the pilot, should reach 750 km./hr. The V.G.-30 single-seater pursuit (Hispano-Suiza 12-Xcrs engine cannons), of the same origin as the V.G.-50, would be produced in series and would attain 650 km./hr. It would be constructed entirely of wood. References in an article mentioning also new British aircraft. *Les Ailes*, April 25, 1940, page 6, 2 illus.

FRANCE

The Bloch Fighters—Sturdy, Radial-Engined Single-Seaters. Bloch 152 C.1 fighter in service with the French Air Force is powered by a Gnôme Rhône 14 N.21 engine developing 1030 hp. at 13,000 ft. It has a top speed of 323 m.p.h., approximate range of 465 miles, and landing speed of 63 m.p.h. Wing span 34 ft. 7 in. Wing loading 31.4 lb./sq.ft. Cowling is of the long-chord scalloped type with flush pepper-box exhausts, and orifice for intake of cooling air is of unusually small diameter. It is known that on certain machines this has been enlarged very considerably which may denote cooling difficulties. Messier retractable undercarriage is raised inwardly and covered by metal plates.

Armament can be varied. There are provisions for four (or possibly six) M.A.C. wing-mounted machine guns (300 rounds apiece), or two Hispano-Suiza 404 20-mm. shell guns (20 rounds each); or both these loads can be carried simultaneously. Hispano gun is of the long high-velocity type, and, when installed in the Bloch fighter, protrudes some distance from the leading edge being provided with large faired supports. History of the Bloch 150, details of the Bloch 151 and 152, and dimensions, weights and loadings, and performance of the Bloch 152 C.1. *Flight*, May 23, 1940, pages 474e–474f, 4 illus., 1 table.

The French Martin. Features and development of the Martin Model 167F reconnaissance bomber are described. Bomber is powered by two Pratt and Whitney Twin Wasp engines and has a maximum speed of 316 m.p.h. at critical altitude. *Flight*, May 30, 1940, pages 494a–494c, 5 illus., 1 table.

The French Douglas. One of the most unorthodox high-speed bombers now in service is the Douglas DB7-B3 as delivered to the French Air Force. Bomber has been designed so that it can be built, stored, and shipped in small compact units. Each half of the wing is made up of four separate sections, the fuselage of three, and the tail unit of seven. Besides simplify-

ing shipment, this feature is extremely valuable in the event of damage as a complete unit can be speedily replaced. Top speed 320 m.p.h. Cruising range 1200 miles. Description, dimensions, weights, and loadings, and performance when powered with two Pratt-Whitney Twin Wasp engines. *Flight*, June 6, 1940, pages 506a–506b, 4 illus., 1 table.

GERMANY

Aerodynamic Brakes of the Ju.88 to Limit Speed in Dives. Aerodynamic brakes on the Junkers Ju.88 are of the shuttered type, normally set in the lower surface of the wing. They are articulated on the spar in front and are lowered more or less, according to the reduction of speed which is to be obtained. The brake is an extrapolation of the braking strips mounted on the single-engine Ju.87. As on the latter, the lowering of the shutters of the Ju.88 automatically acts on the locking device of the flaps which are articulated in the "aerodynamic shadow" of the brakes in the dive. Short note and drawings of airplane and its brakes. *Les Ailes*, May 9, 1940, page 3, 2 illus.

Ago "Kurier" Liaison Airplane. Designed before the war, as also were all the airplanes in service in the German Air Force, this small two-engine airplane on the whole constitutes an excellent machine to assure liaison between officers of the staff. With a total power of 480 hp. it carries a pilot, a radio operator and six passengers, or a movable load of 1200 kg. for an empty weight of 1650 kg. It is equipped for night flying and its landing speed—90 km./hr.—does not appear prohibitive in spite of the high wing loading. The airplane is a low-wing cantilever monoplane. Wing span 13.54 meters. Weight in flight 2850 kg. for a net lifting surface of 25 m.s. With two Argus As-10C. 240-hp. inverted aircooled engines, maximum speed 330 km./hr. at sea level. Cruising speed at 2000 meters 285km./hr. Range at the latter speed 1100 km. Practical ceiling 5200 meters with both engines operating, and 1500 meters with one. Description of construction. *Les Ailes*, May 9, 1940, page 3, 4 illus.

F.W. 189 Two-Engine Observation Airplane. A. Frachet. Focke-Wulf F.W.189 three-seater observation airplane of a modern formula has been designed for cooperation with the artillery to direct the fire, but the Germans intend it also for training of crews, and it is for this use that it is the most interesting. Performances are slightly superior to those of the Henschel Hs.126. Maximum speed is 320 km./hr. near sea level, 357 km./hr. at 2600 meters, and 338 km./hr. at 6000 meters. The airplane climbs to 2000 meters in 4 min., to 4000 meters in 8.4 min., and to 6000 meters in 14.6 min. Practical ceiling is 8400 meters.

Good visibility has been obtained by the adoption of a short and wide fuselage body, almost entirely transparent, in which the pilot, observer, and radio operator are installed. While the F.W.189 presents some advantages over the Hs.126, it is certainly more vulnerable due to its large dimensions. It consists of a central part carrying the body, bound by the supporting girders carrying the tail surfaces and two trapezoidal semi-wings. Armament comprises two fixed machine guns to the front mounted in the central part of the wing, and, to the rear, two other tubes mounted on pivots for firing below and above the horizontal empennage. A movable load of 710 kg. is carried which raises the total weight to 3400 kg. Description, dimensions, and performances. *Les Ailes*, April 25,1940, page 5, 1 illus.

Ju.87 Dive Bomber. A. Frachet. Germany has prepared a very numerous fleet of Junkers Ju.87 two-seater dive bombers of which it has made and continues to make very wide use at the price, however, of heavy losses which are explained by the performances which are insufficient in the presence of modern pursuits. The Ju.87 resembles the Loire-Nieuport 140 designed in France some years ago, and was revealed in Germany in 1937. Aerodynamic brakes, as in the Ju.88, are small planes suspended beneath the principle wing spar. One of the bomb racks is mounted under the fuselage and carries, on a guiding fork, a 500-kg. projectile. Four others are wedged in under the half wings with 50-kg. bombs. Pilot operates two machine guns located in the center section of the wing. Description.

Jumo 211 1200-hp. engine. Weight empty 2770 kg. Movable load 1450 kg. consisting of 570 kg. of fuel, and a maximum of 700 kg. of bombs. Maximum speed 390 km./hr. Cruising speed 320 km./hr. Minimum speed 108 km./hr. Climb to 4500 meters in 10/12 min. Ceiling 8500 meters. Range with reduced load of projectiles 800 km. *Les Ailes*, June 6, 1940, page 3, 3 illus.

News from Germany. German Air Ministry has released detailed particulars of some of the standard military aeroplanes in service with the Luftwaffe. Armament, crew, engines, dimensions, weights, performances, and photographs, in some cases, are presented for the following: He.115 reconnaissance 3-seater seaplane (two B.M.W. 132De engines giving 1690 hp., maximum speed 217 m.p.h.); He.111K Mk.V 4-seater bomber (two D.B.601 engines giving 2140 hp., maximum speed 274 m.p.h.); Do.24 five- or six-seater reconnaissance and bombing flying boat (three B.M.W. 132 engines giving 2280 hp., maximum speed 195 m.p.h.); Do.17 three-seater long-range reconnaissance bomber (two D.B.600G engines giving 2100 hp.); Messerschmitt "Jaquar" four-seater long-distance bomber (two D.B.601 engines, span 55 ft., armament of three cannon and two machine guns); He.118 two-seater dive bomber (Mercedes D.B.600 engine giving 1070 hp., maximum speed 261 m.p.h., four machine guns in wing, movable gun in rear cockpit, 20 22-lb. bombs for attack and one 1100-lb. bomb for dive bombing); Ju.86K four-seater bomber (two B.M.W. 132Dc engines giving 1690 hp., maximum speed 239 m.p.h., three machine guns and 2200 lb. bombs). *Aeroplane*, May 31, 1940, page 735, 7 illus.

New German Equipment. Latest Messerschmitt Me.115, according to an Italian source, is said to be very similar to the Me.109 and to be manufactured on many of the jigs and tools made for the latter. It gives the impression of being an Me.109 with clipped wings, span being only about 31 ft. Wings are of a different shape and a new type of flap is used. Machine has a Daimler-Benz 1200-hp. engine and appears to be very fast and, in the hands of the test pilot, fairly maneuverable.

It is also said that Do.215's are soon to be fitted with D.B.603 1500/1700-hp. engines, these engines being produced on a large scale to be in service by the end of the year. The 2000-hp. D.B.605 engine has not been particularly successful and the aircooled radials of 1500 hp. have not proved very satisfactory either.

Of the He.113 fighter it is said that the wing area has been reduced to 155.75 sq.ft. (wing span 30 ft. 10 in., length 26 ft. 11 in., and height 8 ft. 2 in.). Engine is the D.B.601S of 1200/1300 hp. and armament comprises one shell gun on the engine and two large-bore synchronized machine guns in the center section. Brief note only. *Flight*, May 30, 1940, page 492.

ITALY

Italy's Air Force. Even the newest of the Italian single-seater fighters are radial engined machines in which speed has been subordinated to maneuverability. Armament too follows the American idea of two large-bore machine guns (actually 12.7-mm. Breda SAFAT) mounted in the fuselage and synchronized to fire through the propeller arc. Explosive ammunition is believed to have been developed for these guns. Italian policy is said by Gabrielli to be to keep down the number of machine guns to a minimum; if authorities could find some positive safeguard against jam, the G.50 would have only one gun. Loading and firing of the guns is sometimes effected by a twist-grip attachment on top of the control column. Italy has experimented with anti-aircraft bombing. Bombing development has been notable for the retention of the three-engine formula. The Cant Z.1007 series now coming into service are fitted with three engines.

Drawings show the installations of the 12.7-mm. Breda SAFAT gun on the Cant Z.501, and of a similar gun mounted to fire through the floor on the Z.506B, as well as the Caproni 165, Reggiane Re.2000, A.U.T.18, Caproni Vizzoli F.5, Piaggio four-engine P.50, Piaggio four-engine P.108 (?), Piaggio P.123, and Caproni Ca.133. Total Italian strength in the air is estimated at something over 3000 machines, including naval aircraft, reserves, and advanced trainers.

Duties, design, engine, armament, characteristics, and performances as well as a photograph are given for many military airplanes. *Flight*, June 13, 1940, pages 528a–528d, 29 illus.

THE NETHERLANDS

Fokker's Yesterday. Account of a visit to the Fokker plant just before the invasion and comments on some of its products, including: three versions of the G.1 two-engine fighter; T.8-W torpedo-dropping float seaplane (two Wright Whirlwind 450-hp. engines); T.9 heavy bomber (two 1375-hp. Bristol Hercules engines, top speed around 300 m.p.h.) which was the most powerful two-engine bomber yet built; and the D.23 single-seater two-engine-in-tandem tricycle fighter (two 540-hp. Walter-Sagitta engines arranged as tractor and pusher) which the Fokker company hoped to develop much farther, top speed of low-powered prototype being 326 m.p.h. *Aeroplane*, May 24, 1940, pages 704–709, 15 illus.

U. S. A.

Aviation Sketch Book of Design Detail. Drawings show wing root on the side of the fuselage of the Ryan STM-2 trainer, cross-section of the fuselage revealing the semimonocoque stressed-skin type of construction used, and landing gear of the treadle type with mechanically operated multiple disc brakes and long-stroke oleo and spring shock absorbers. Drawings are also given for the retractable wing-tip landing floats showing method of retracting, as well as the interior of the fuselage, of the Consolidated Model 28 twin-engine flying boat. *Aviation*, June, 1940, pages 60–61, 5 illus.

Boeing Stratoliners for TWA. Long description of the Boeing 307-B four-engine Stratoliners with special regard to performance, altitude conditioning, and passenger accommodations. Table of performances is included. *Aero Digest*, June, 1940, pages 46–47, 162, 7 illus., 1 table.

Details of the Sikorsky Helicopter. The experimental VS-300 helicopter has a gross weight of 1150 lb. and is powered by a 75-hp. Lycoming engine. It has no fixed surfaces and its lift, stability, and control characteristics are based on aerodynamic forces applied to its fast-rotating main and auxiliary rotors. Forward velocity is completely excluded as a factor necessary to the control characteristics of the machine. Rotor blades at their most effective position travel at a speed of 250 to 300 m.p.h. and this velocity is present whether the machine is hovering or moving forward, thus giving a perfect basis for powerful and effective control under all conditions. Lifting and control members of the machine consist of a single lifting rotor of 28-ft. diameter and operating at 255 r.p.m., and three small auxiliary rotors or airscrews, supported by an outrigger and placed beyond the disc of rotation of the main rotor. Auxiliary rotors have a diameter of 6 ft. 8 in., and operate at 1700 r.p.m. The VS-300 helicopter is described, and the synchronization system, wide spheres of usefulness, and possibilities for a larger two-seater helicopter powered with a 200-hp. engine are discussed. *Aero Digest*, June, 1940, pages 56–57, 3 illus.

The Ercoupe. Simplicity in flying is said to have been achieved in the Ercoupe two-seater tricycle low-wing monoplane by eliminating the rudder pedals, the airplane being controlled entirely by the control wheel. Ailerons, rudder, and nosewheel are all mechanically coordinated so that turning is accomplished in the air, as it is on the ground, by turning the wheel right or left. Continental A-65 engine. Wing loading 8.2 lb./sq.ft. Wing span 30 ft. Maximum speed 117 m.p.h. Landing run 200 ft. *Aero Digest*, June, 1940, page 99, 3 illus.

Fleet Model 60 Advanced Trainer. Model 60 two-seater advanced trainer now ready for export, is a low-wing monoplane of all-metal construction having semi-cantilever wings with external bracing. Net wing loading 18.1 l../sq.ft. Maximum speed 190 m.p.h. Landing speed 58 m.p.h. Rate of climb 1150 ft./min. Jacobs 330-hp. engine. Long description of airplane with weights, loadings, and performances at 3900 lb. *Aero Digest*, June, 1940, pages 65–66, 87, 3 illus., 1 table.

Republic EP-1 Pursuit. With cruising range of 750 miles at a speed of 290 m.p.h., the EP-1 single-seater low-wing monoplane may be destined to take an active part in the defense of Sweden. It conforms in general design to the P-39 pursuits. Armament includes two machine guns mounted on the fuselage and synchronized to fire through the propeller, two machine guns mounted on the wings and firing explosive bullets, plus ten 17-lb. bombs attached to the lower surface of the wing. Integral fuel tank is formed by the wing structure itself. This portion of the wing is made gas-tight by use of a special sealing compound, and the structure in this area forms the end walls and baffle plates, this being in the center panel. Description but no characteristics and performance figures. Cutaway drawing showing location of armament and other equipment is included. *Aviation*, June, 1940, pages 52–53, 3 illus.

Spartan Primary Trainer. Model NS-1 two-place biplane primary trainer has been developed for military usage and conforms to the structural requirements of the U.S. Army Air Corps and the Bureau of Aeronautics. Lycoming R-680-7 220-hp. engine. Wing span 33.71 ft. Maximum speed 126 m.p.h. Landing speed 47.5 m.p.h. Short description, characteristics, and performance. *Aero Digest*, June, 1940, page 95, 2 illus.

Aircraft. Performance, specifications, accommodation, equipment, costs, and special features, as well as a photograph are given for the following aircraft in a form for cutting and filing: Aeronca "Chief" S-65C seaplane; Beechcraft D17S; Beechcraft E17B; Cessna Airmaster C-165; Ercoupe 415C; Fairchild 24-W40; Fleetwings Seabird F-5; and Porterfield 90-W. *Popular Aviation*, July, 1940, pages 47–50, 8 illus.

Aircraft, Manually Propelled

A German Apparatus for Manually Propelled Flight. The Schedel "Libellule" is an ornithopter with flapping wings in tandem and has been designed for propulsion by the muscular force of the operator. It comprises four wings, two large ones to the front and two others a little smaller to the rear. These wings are connected rigidly two-by-two by coaxial casings, each pair of wings being mounted as the beam of a balance. In flight the two pairs of wings should execute movements of oscillatory rotation symmetrical

around their common axis of articulation. These movements would continuously engender a horizontal and a vertical component. The Schedel apparatus of about 10-meter wing span is given a Goettingen 535 profile. Description and drawing. *Les Ailes*, April 25, 1940, page 8, 1 illus.

Air Transportation

Looking Forward—Prolegomena for a Detailed Study of the Future of British Civil Aviation. H. R. Cox. Next big advance in operational speed for aircraft on the transatlantic route is suggested as 300 m.p.h., and the author urges the construction of a 300-m.p.h. overnight mail plane. Three possible schemes are discussed as goals at which to aim for this service. They are combinations of the possible overnight North Atlantic Services outlined in a table. Degree of comfort for the passengers, number of passengers to be carried, frequency of service, speeds and ranges to be considered by the designer, selection of route, and possibilities of refueling in the air are also discussed in connection with the transatlantic route. Aircraft requirements for the route to the East and for European and internal routes are also considered. Reports of various committees on British civil aviation are summarized, the aims of British civil aviation are presented, and a controlling authority for civil aviation is proposed. To be continued. Wilbur Wright Memorial Lecture of the Royal Aeronautical Society. *Flight*, June 6, 1940, pages 509–513, 2 illus., 4 tables.

The pre-war era; the job to be done; safety requirements and the route; the Atlantic route; take-off problem; Empire route to Africa and the East; European routes; national routes; regulation and safety; aero motors; structures; flutter; flying tests; design and construction; design initiative and policy; influence of the propeller position. To be continued. *Aeroplane*, June 7, 1940, pages 763–765, 3 illus., 1 table.

A Policy for Civil Aviation. H. R. Cox. Very large airplanes, to be efficient, will be all-wing airplanes, and arguments for this opinion are presented. At 380,000 lb. there would be no need for a fuselage. True all-wing airplanes would be big. There would be gains in performance obtained by utilizing the wing for stowage. Question of landplane or seaplane, pressure cabins, study of wing forms, organization, nature of future investigations, a plan for civil research, and education and training are discussed. Continued. Royal Aeronautical Society paper. *Aeroplane*, June 14, 1940, pages 798–800, 5 illus.

Chicago and Southern—"The Valley Level Route." R. S. Gall. Development and operation of the Chicago and Southern Airlines over the Mississippi Valley during the past four years, including equipment used and maintenance activities, such as propeller overhaul, and equipment of the engine shop. *Aero Digest*, June, 1940, pages 42–45, 161, 12 illus.

French Commercial Aviation since September, 1939. Statistics of French air-transport traffic from September 3 to December 31, 1939, and for 1939 up to September 3 are given in tables, and lines operated are discussed. *L'Aéronautique*, April, 1940, pages 109–118, 10 illus., 3 tables.

Gliders and Gliding

Soaring on the West Coast. C. F. McReynolds. Account of the third annual Western Championship Soaring Contest held at Arvin, California, April 13–21, with discussion of notable technical contributions to sailplane design, made by several builders, and the McReynolds-Barnhart pneumatic-thermometer thermal sniffer. *Aviation*, June, 1940, pages 34–35, 102, 10 illus.

Propellers

Hamilton Standard's Facilities for Testing Propellers. New test house is a reinforced structure covering an area of approximately 13,800 sq.ft. and including four propeller test chambers, the two having an inside diameter of 24 ft. permitting tests of propellers for engines up to 5000 hp. Most efficient arrangement, as determined by a $^1/_{12}$-scale model test chamber, was found to be one in which air flows through the test chamber in a straight line without going around corners. The test chambers therefore have their air intakes and exhaust stacks arranged horizontally and in a straight line. Equipment is described including the suspension type engine stand, control of engine cooling independently of air furnished by the propeller, vibration dampening, oil flow control, and signaling system to indicate whether air sufficient for cooling is reaching the engine. *Aero Digest*, June, 1940, pages 50, 161, 2 illus.

Charting Propeller Efficiency. R. J. Hoffman. To compare characteristics of high-speed propellers, a formula is given that uses the generally available design factors of flying speed, brake horsepower, and engine r.p.m. Coefficient found from these data is the speed-power coefficient. One diagram shows that increasing the number of blades decreases the propulsive efficiency of the propeller. For the same solidity, however, the efficiency of a three-bladed propeller is higher than the efficiency for a two-bladed propeller, as shown in another diagram. Solidity is defined as the ratio of total blade area and propeller disc area. Speed-power coefficients of two-, three-, and four-bladed propellers are plotted with their respective slip functions, all having the same blade layout.

Another diagram shows the higher efficiency for a tandem arrangement than for a four-bladed propeller having the same solidity. Equal division of the power is a primary advantage that may be accomplished by setting the rear propeller blades at a slightly lower incidence. Spacing of tandem propellers should not be less than 15 per cent of the diameter, since closer spacing will lower the efficiency as indicated in another diagram. Schematic cross-section of a dynamometer for testing tandem propellers is presented, in which one propeller shaft is directly connected to the armature of an electric motor and to a bevel gear which drives two pinions and a bevel gear in reverse direction. *Popular Aviation*, July, 1940, pages 53, 90–91, 9 illus.

The Latest Rotol Airscrew. New Rotol constant-speed propeller described was designed for the fast single-engine fighters of the Royal Air Force and is now in production and in service with the squadrons. It has a pitch range of 35° and, though not a feathering propeller, it can easily be adapted for feathering by the fitting of a feathering pump and a cylinder with longer stroke to give the increased pitch range then required. It is known as the "external-cylinder" type of Rotol propeller as the pitch-changing mechanism is outside the hub—in front of it—though covered by the spinner. Like that of the "internal-cylinder" 20°-type the mechanism is worked hydraulically by engine oil, controlled by a governor-pump unit with centrifugal governor, whose design remains unchanged. Wooden blades may be fitted instead of those of magnesium alloy.

Thread on the magnesium-alloy blade is of interest as it has been specially evolved for use with this alloy. Its form gives the root of the thread in the alloy a much more liberal radius of curvature than is provided in the usual V thread. Buttress threads, designed to take big loads in one direction, can be noticed in several places in hub and housings. Both propeller and governor-pump unit are designed to work in either direction of rotation. Description and sectional drawing of propeller. *Flight*, May 23, 1940, pages 472–473, 3 illus.

Equipment

New Equipment. Electronic Laboratories instrument-panel lighting installation using ultra-violet lamps. Conlon navigation watch which so combines mean-time readings with sidereal time indications that no conversion tables or computation are required to obtain the elapsed mean, or elapsed sidereal, time. SKF's new type of crankshaft bearing for aircraft engines. Gunk cold-tank solvent for "piston varnish." FabriSteel "Fast-On" lock nuts providing a new method of increasing the thread area in sheet metal, making practical the use of lighter gages and simplifying assembly in inaccessible places. Aero Time Recorder useful for keeping an accurate check on flying time, for navigation purposes, and instrument flying. Fairchild Model F-58 aerial roll-film contact printer eliminating the use of several high-wattage incandescent lamps, being equipped, instead, with a large number of 2.5-watt Argon glow lamps. New Aircraft Precision hydraulic surge chamber, main landing-gear strut, and tailwheel shock strut. Champion wind-driven 6-volt generators of 6-, 12-, and 20-amp. capacity and weighing 6, 9, and 13 lb., respectively. Pesco hydraulic flow equalizer which distributes fluid equally from a common pressure line into two discharge lines. Long description of the instrument-panel lighting installation and few details of other equipment. *Aero Digest*, June, 1940, pages 138, 141–142, 145, 7 illus.

Buyer's Log Book. Anilol automatic metering valve for automatically raising the octane value of gasoline for take-off and deicing carburetors in cold weather. Aircraft Tools flush-type countersunk rivets. Wilson "Hornet" arc welder. Savage nibbler. SKF roller bearings. Durakool mercury-relay switch. Aeromac oil-dilution valve operated by electric solenoid and designed for diluting crankcase oil with aviation gasoline to assist in cold weather starting. Aero Starters electric starter for light airplanes. Champion light-weight wind-driven generators. Very brief notes on this equipment. *Aviation*, June, 1940, pages 74–75, 9 illus.

Aircraft Instruments and Navigation

Flight Co-ordinator. Flight Co-ordinator devised by Cox and Stevens Aircraft Corporation enables the pilot to determine quickly the relation between speed, fuel consumption, and engine and propeller settings in level flight at any altitude and temperature. It also indicates operating limits of the airplane and engine, efficiency of the flight, and maximum cruising speed obtainable at various altitudes. In airplanes with engines having two or more blower ratios it shows the pilot at what altitude he should change blowers. Co-ordinator consists essentially of a flat base, on one side of which are arms or discs on which are inscribed scales from which the settings are made and readings taken. On the other side is usually a circular slide rule, map scale or conversion tables for the pilot's convenience. Instrument is described, a particular problem is worked out as an example, and other flight instruments developed by the company are mentioned. *Aero Digest*, June, 1940, pages 84, 87, 2 illus.

Navigation

Problems of Time in Navigation. T. P. Conlon. As a solution of the difficulties of keeping exact time, a fictitious sun, called the "mean sun" is supposed to move in the equinoctial with a uniform velocity equal to the mean velocity of the earth around the sun. This "mean sun" time is the time kept by clocks and watches according to standard time zones. Having established, as the case may be, either the position of the sun, or the position of any other celestial body, and the civil or sidereal time at Greenwich, at the moment of the observation, the position of the celestial body is considered as "frozen" in the celestial sphere. Time then loses its value as time, and becomes simply an angular measurement. True reasons for each movement that must be accounted for in celestial navigation are examined in detail. *Aero Digest*, June, 1940, pages 48–49, 5 illus.

Research on a Calculator of the Astronomical Point. A. Bastide. First research project was undertaken in 1930 to establish a graphical method sufficient for the aerial navigation of the Dakar-Natal line over the South Atlantic at night. Sidereal routes for navigating the Dakar-Natal, Paris-New York and Aoul'ef-Gao (Sahara) routes are considered, and the graphs and the calculating machine are described and illustrated. Criticisms of the method are presented. Second project, started at the end of 1932, concerned the development of a calculator which is described. This project did not sufficiently satisfy actual and near conditions of aerial navigation, and so a third project was undertaken.

There have successively been adopted: the "Latitude" board with star graphs (sidereal chart) and coordinates of height and local sidereal time; and the "Star" board with graphs of latitudes and coordinates of height and local sidereal time. The third system retains the "Star" board with graphs of height and coordinates of latitude and local sidereal time.

The author's system allows a much better general utilization of these graphs than that offered in the Weems Album, and also the machine permits the marking of the point on a transparent map with the Mercator projection. The machine utilizing the orthodrome curves constructed on the same rectangular axes permits the mechanical application of the Marq Saint-Hilaire method for establishment of a base line whatever the planet observed may be. *L'Aéronautique*, April, 1930, pages 120–126, 7 illus., equations.

Electrical Equipment

Ancillary Power Services. Comments on behalf of the electrical installations in aircraft, and of the so-called high-frequency a.c. type in particular, are given by F. E. Butcher in a discussion of the Royal Aeronautical Society paper by R. H. Chaplin and F. Nixon. Mr. Butcher considers 800-cycle frequency unnecessarily high and that the 400-cycle frequency is likely to be finally settled upon when taking generation problems into account. Ground tests at 50 cycles and induction motors, because they cause no radio interference, are recommended. Trend in America is towards a 24-volt system and a.c. seems to be on the way out, according to the comment made by G. Hausamann of Eclipse. *Aeroplane*, May 24, 1940, page 712, 1 illus.

Fuel Lines

Air Ministry Notices. Notice No. 5, entitled "Flexible Tubing for Use in Aircraft Fuel and Oil Systems," indicates the approved purposes for which Petro-Flex, Avioflexus, and Superflexit tubing may be used, and gives regulations regarding supervision required in the fitting of new lengths necessary under special circumstances, minimum radii to which these flexible tubes may be bent when installing on aircraft, including also those for reinforced

Avioflexus, and precautions to be taken in connection with the fitting of flexible tubing on aircraft (preparation, installation, protective coating, electrical bonding, and avoidance of binding of the union nut). *Aircraft Engg.*, May, 1940, page 162, 1 table.

Ice Elimination Equipment

Air-Equipment Pump for Deicing the Propeller. Pump comprises essentially an aluminum-alloy housing on which is fixed an electric motor driving a reduction gear controlling the camshaft. Cams control the displacement of two tappets which are displaced in guides determining a reciprocating movement of the diaphragms closed between discs and maintained on the housing by the fastening of the cover. Suction and delivery valves consist of balls. The deicing fluid, admitted in the vessels by channels, is delivered by movement of the membranes and change of the pump. Description and drawings of the pump parts, installation layout, and cross-section. *L'Aéronautique*, April, 1940, page 119, 3 illus.

Parachutes

Pioneer Parachute Pack. F. Smith. The 1940 model of the 1918 parachute has some operating faults that have existed through the years. These faults are referred to and a few details of the Pioneer P-1-B parachute pack are given. New method of packing the parachute is said to prevent the following: fouling of the suspension lines over the canopy; canopy opening inside out, or partially so; and suspension line snarling by unequal removal from the pack. *Aero Digest*, June, 1940, page 92, 2 illus.

Schoffner Safety Parachute. German parachute consists of two coaxial canopies with a connection between them in the polar region and with separate cords suspending the load. The parachutist, by acting on the cords for maneuvering the parachute joined to certain other cords can also reduce the passage between the surfaces at a point. This results in a possibility of dissymmetry serving to modify the trajectory of the descent. At the same time, this maneuver avoids the always troublesome pendulum movements and permits the speed of descent to be changed. Brief note and drawings. *L'Aéronautique*, April, 1940, page 140, 2 illus.

Testing Apparatus

Lightning Recording Instruments. J. H. Hagenguth. Instruments developed for studies of natural lightning, notable application to the Empire State Building, and features of design, operation, and performance. General and oscillographic requirements are considered, and the designs of the cathode-ray oscillograph for recording lightning currents of high amplitude and short duration, of the delay cable, and of the shunt are described in detail. To be continued. *General Electric Rev.*, May, 1940, pages 195–201, 12 illus.

Merrill Laboratories Design Electronic Wheel Balancer. Apparatus described was developed for determining the direction and approximate amount of unbalance of a vehicle wheel while that wheel is in position on the vehicle. It consists essentially of a pick-up device, an amplifier, a stroboscope, a driving and brake unit, and a rear-wheel support. It can be used to determine whether the wheel is in static balance and also whether it is in dynamic balance. It will indicate bad wheel bearings and eccentric and bent wheel assemblies. *Automotive Industries*, May 1, 1940, page 416, 1 illus.

The Month's New Instruments. New devices for measurement, inspection, testing, metering, and automatic control. Short descriptions. *Instruments*, May, 1940, pages 114–123, 126, 33 illus.

Temperature-Measuring Equipment. Directory of manufacturers for the following: mercury-in-glass and similar thermometers; bimetallic thermometers; pressure-spring thermometers; resistance thermometers; thermoelectric pyrometers; optical thermometers; radiation pyrometers; and automatic control equipment. Books on heat and temperature measurement and code for addresses of manufacturers are included. Potentiometers and other meters, optical pyrometers, radiation pyrometers, and automatic control equipment are illustrated. *Jour. Applied Phys*, June, 1940, pages IV–XX (alternate pages), 42 illus., 7 tables.

Thermoelectric Thermometry. W. F. Roeser, National Bureau of Standards. Fundamental laws and theories of thermoelectric phenomena and their historical development as well as the application of these phenomena to the measurement of temperature are discussed in considerable detail, including: fundamental laws of the homogeneous circuit, of intermediate metals, and of successive or intermediate temperatures; historical investigation and theory; thermoelectric thermometers; types and reproducibility of thermocouples; temperature-e.m.f. relations; principles of millivoltmeters and potentiometers; protection tubes and causes of changes in thermoelectric characteristics of materials; calibration of thermocouples; measurement of temperatures; and installations (general precautions, location of thermocouples, common return, use of a zone box, thermocouples purposely insufficiently immersed, and measurement of average temperature). *Jour. Applied Physics*, June, 1940, pages 388–407, 8 illus., 3 tables, 14 equations.

Materials

New Developments in Automotive Materials. New Victor gasket combining the desirable properties of asbestos and Neoprene, and, when immersed in extreme-pressure lubricants for 500 hours at 200°F., showing no disintegration, blistering, dimensional changes, loss in flexibility, or delamination (description of manufacturing processes and test results). Improved Magnaflux device for detecting metallurgical defects in automotive parts and installed in the Cadillac-LaSalle laboratory. Scott testing machine used to indicate load compression on latex sponge products. Acheson surface treatment for non-conducting materials, such as phenolic products, wood, and ebonite, permitting such materials to be electroplated.

Colaweld Metaljoiner said to provide a simple, efficient, high-speed, and economical method of joining metals, such as aluminum and its alloys, steel, copper, brass, monel metal, stainless steel, zinc, tin, and silver. Jessop cold-heading die steel said to eliminate the porous center of cast ingots. Acheson stable and highly adherent lubricating coating for use in prelubricating surfaces not readily lubricated by ordinary means. Results obtained by various experimenters when adding titanium to cast iron (abstract of article by P. Bastien in "Chimie et Industrie"). A method of bearing production that ensures a good bond between backing and lining (abstract from "Tin and Its Uses" of the International Tin Research and Development Council). Brief descriptions of these materials but long abstracts. *Automotive Industries*, June 15, 1940, pages 552–555, 587, 4 illus.

Metals

Corrosion and Protective Coatings

The Materials Corrosion Investigation at Eastport, Me. W. J. Jeffries. Brief summary of results of investigation started in 1936, and graphs showing: relative order of resistance to corrosion in simple exposure 1937–38 in air, at mean tide, and submerged; effect of electrolytic action on rates of corrosion on dissimilar metals in contact in compound exposure 1937–38 at mean tide and submerged; and relative order of resistance to cavitation erosion in sea water as determined from vibratory tests at M.I.T.

Metals under test included: brass or bronze; aluminum bronze; Sn bronze with Pb or Ni; Cu-Si alloy; Cu-Zn with Mn; Zn bronze with or without Pb; nickel-copper; pure metals (Cu and Zn); non-metallic materials; cast iron; alloy iron; steel; cast steel; welded steel; alloy steel; and Cr types and Cr-Ni types of corrosion-resisting steel. *Am. Soc. Naval Engrs., Jour.*, May, 1940, pages 295–300, 3 illus.

Flame Cleaning, Dehydrating, and Descaling. J. G. Magrath. High-temperature scales; variations in scale; scale replaced with rust; removal of rust; essentials of dehydration; procedure of flame cleaning and dehydration; dehydration and maximum scale-lift provided; wire brushing; advantages of the process; paint burning and surface conditioning; power wire brushing; oxyacetylene process of flame descaling; combination pickling and flame descaling; and application to forgings. International Acetylene Association paper. *Heat Treating & Forging*, May, 1940, pages 217–221, 235–236, 3 illus.

Electroplaters Meet. Short abstracts of papers presented at the American Electroplaters' Society Meeting. First issue—"Metallurgical Aspects of Hydrogen in Electroplating," C. A. Zapffe and C. L. Faust. "Magnesium as a Control Agent for Zinc Anodes," R. O. Hull. "Notes on the Spot Test for Thickness of Chromium Coatings," W. Blum and W. A. Olson. "Disposal of Plating Room Wastes," T. J. Fadgen. "Magnesium Copper Sulphide Rectoplaters as a Source of Direct Current Power for Electroplating," C. A. Kotterman and W. Binai.

Second issue—"Relationship of Cleaning Techniques and Adhesion of Electrodeposits," B. F. Lewis. "Plating and Heating of Zinc Base Die Castings," F. F. Oplinger. "Pickling of Metals for Electroplating," O. T. Towner. "Effect of Moving Cathodes," W. M. Phillips. "Silver Plating at Very High Current Densities," A. C. Simon and J. T. Lumley. "Cathodic Treatment of Copper in a Solution of Beryllium Sulphate to Prevent Tarnishing," D. T. Ewing and G. W. Jernstedt. *Iron Age*, June 27 and July 4, 1940, pages 43–45 and 41–43, 4 illus.

Iron and Steel

The Iron and Steel Institute (British). Brief abstracts of papers presented and discussions. First issue—"Researches into the Structure of Alloys," A. J. Bradley and C. Sykes, dealing with investigation of the equilibrium diagrams, theory of order-disorder transformation, and experimental investigation of the theory using alloys β-brass, Cu_3Au, CuPd and Ni_3Fe. Short abstract and discussions by W. H. Hatfield, W. Hume-Rothery, D. A. Oliver, and C. H. Desch. Also abstract and discussion of the paper entitled "The Manufacture of Pig-Iron in America," by W. A. Haven.

Second issue—"Anti-Piping Compounds and Their Influence on Major Segregation in Steel Ingots," E. Gregory. "Heat Transfer in the Flow of Gas through a Bed of Solid Particles," O. A. Saunders and H. Ford. "Method of Sclero-Grating Employed for the Study of Grain Boundaries and of Nitrided Cases; Grain Structures Revealed by Cutting," O. W. L. Ljunggren. Discussions are by W. H. Hatfield, C. H. Desch, and others. *Engineering*, May 10 and 24, 1940, pages 488–489 and 517–518.

Nonferrous Alloys

Aluminum Alloy Practice in Europe. E. V. Pannell. Aluminum casting alloys used in Britain and the Continent, types of additive elements, and the uses to which such alloys are put are described. Composition and general physical characteristics are given for some 70 alloys. Survey of the list indicates that it could be reduced to less than half if duplications were eliminated. Small differences of analysis are indicative of the individualistic attitude of producers and foundries, but these are gradually being leveled out by the standardization called for under Government control. The many compositions of foundry alloys in use containing small amounts of magnesium manganese, chromium, and similar elements are explained by the fact that much of the metal coming into the foundries is scrap from aircraft sheet-metal shops. These elements are kept under analytical control, however, and afford a simple means of producing castings for heat treatment. *Iron Age*, June 13, 1940, pages 25–29, 1 illus., 2 tables.

A General Utility Casting Alloy. A. Dunlop. Continued discussion of five per cent nickel bronze. Effect of mass on response to heat treatment is dealt with and modifications which have been developed for the heat-treatment operation are described. Data are presented which show that sections up to 4 in. in thickness can be treated quite successfully. Bearing characteristics and corrosion resistance are considered. *Metal Industry*, June 7, 1940, pages 497–499, 3 illus., 4 tables.

Heat-Treating Light Alloy Castings. H. G. Warrington. Heat treatment of light-alloy castings is reviewed from the practical aspect as seen by the heat-treatment technician and the engineer who is desirous of applying castings in the most efficient manner. Discussion covers: critical quenching rates; heat-treatable alloys; complex alloys; general heat-treatment considerations; distribution of stresses; operation at elevated temperatures; reduction of quenching temperature; and a treatment for very large castings as well as results obtained with it. To be concluded. British Institute of Metals paper. *Metal Industry*, June 7, 1940, pages 493–496, 2 tables.

Heat Treating Light Alloy Castings. H. G. Warrington, High Duty Alloys, Ltd. Changes in microstructure produced by heat treatment are dealt with and different types of furnace equipment now used for heat-treatment purposes are surveyed. Differences between alloys of Group II and the simple solid-solution type are illustrated by photomicrographs of alloy to D.T.D. Specification 131A, and to alloy D.T.D. 304, both in the as-cast and heat-treated conditions, respectively. Microstructures are also shown which were obtained with material to D.T.D. 131A overheated to 545°, 550°, and 555°C., as well as D.T.D. 309 severely chilled die casting in which internal shrinkage occurs. Concluded. *Metal Industry*, June 14, 1940, pages 518–521, 12 illus.

The Fabrication of Magnesium Alloys. L. G. Day. Suitable sand-casting alloys, prevention of porosity due to interdendritic shrinkage, and the need for superheating melts are considered. Die-casting, extrusion, forging, and pressing are also dealt with. Tables given show composition and properties of magnesium casting alloys, and of some magnesium wrought alloys, and effect of superheating on mechanical properties of magnuminium 220, specifications DTD 136A and 281. To be concluded. *Metal Industry*, May 10, 1940, pages 421–424, 4 illus., 3 tables.

Magnesium and Its Alloys. F. A. Fox. Production process used by Magnesium Elektron, Ltd., properties of magnesium, modulus of elasticity, machinability, corrosion, and effect of aluminum as an alloying constituent are discussed by the chief metallurgist of the company. Liability of magnesium to corrosion has in the past been much exaggerated due to the accidental presence of chloride flux inclusions in the metal and to the difficulty encountered in production of a good protective coat on the metal surface. Improvement has been generally recognized now to the extent that the British Air Ministry will permit the use of magnesium-alloy castings and fabrication on seaplanes. To be continued. *Metal Industry*, June 14, 1940, pages 513–516, 7 illus.

Light Alloys Research. Long description of the new laboratories of High Duty Alloys, Ltd., including: spectrographic, X-ray crystallographic, radiographic, and metallographic laboratories; routine mechanical testing; experimental testing; chemical and colorimetric laboratories; corrosion and protection; damping laboratory; experimental heat-treatment department and rolling mill; experimental foundry; instrument workshop; and library and information department. *Metal Industry*, May 10, 1940, pages 409–414, 6 illus.

Testing of Metals

Portable Magnetic Crack Detector. New crack detector placed on the market by the Metropolitan-Vickers Company is in the form of a thin hollow disc-shaped container filled with dust-laden oil and provided with one or both sides transparent so that the concentrations can be observed. It is only applicable to flat surfaces. Short description. *Iron Age*, June 20, 1940, page 39.

Testing Gear-Wheel Material. A. Meldahl. New apparatus developed by Brown Boveri for testing gear-wheel material is described and some results of tests are given. It is shown that the direction of sliding movement plays a preponderant part in the durability of the material. Test rollers are mounted on two heavy shafts also carrying the eccentric coupling gear wheels. Two shafts lie in half bearings in a hinged frame, and two cylinders are pressed against each other with whatever force is desired by means of a lever loaded with weights. Test rollers, bearings, and gear wheels are amply lubricated with oil kept at constant temperature from an oil pump with separate drive. Results obtained in regard to damage by seizing and by pitting, and lubrication are analyzed. In order to investigate more completely the resistant character of the addendum arc, further tests which are described were carried out with somewhat different apparatus. Appendix gives the kinematics of the new test apparatus.

No statement can yet be made as to what a material will really support on an addendum arc, and the author is at a loss to furnish a plausible explanation of why the same material should support such exceptionally different stressings according to the direction of the sliding movement. Results with soft steel, hard chrome-nickel steel, carbon steel, and nickel steel are referred to. From "Brown Boveri Review," October, 1939. *Am. Soc. Naval Engrs., Jour.*, May, 1940, pages 320–329, 14 illus., 7 equations.

Plastic Yielding and Fatigue of Ductile Metals. A Criterion and Its Application. R. W. Bailey. Based upon a hypothesis of surface anisotropy of an otherwise isotropic material, a criterion of the yielding of a ductile metal is suggested which embraces the several well-known criteria as special cases. This criterion for a system of principal stresses X, Y, Z ($= 0$) takes the form $(X - Y)^2 + \alpha(Z - X)^2 + \alpha(Y - Z)^2 =$ constant; or $X_2 + Y_2 - (2/l + \alpha)XY =$ constant. For component shear and direct stresses, q and f, respectively, this becomes $f^2 + 2\left(\frac{2+\alpha}{1+\alpha}\right)q^2 =$ constant, where f/q must fall in the range $\sqrt{2}$ to 2.

Proposed criterion is considered to be applicable in character to fatigue of a ductile metal, and it is applied to derive, from direct and shear stress fatigue test results, limiting fatigue stresses for any combination of shear stress and direct stress in phase, which is the most severe condition. Analysis indicates that the presence of static shear stress may increase the ability of a steel to withstand reversing direct stress. Apparently an opposite effect occurs when direct stress fatigue test results conform to the Goodman or modified Goodman diagrams. *Inst. Mechanical Engrs., Jour. & Proc.*, May, 1940, pages 101–107, 9 illus., 1 table, 5 equations.

The Research Laboratories of Messrs. High Duty Alloys, Limited. New laboratory buildings, which are devoted to research on light alloys, the equipment of the spectrographic department, and of the X-ray crystallographic, experimental physical testing, general and research chemical, and experimental heat-treatment laboratories, and radiological inspection methods are briefly described. *Engineering*, May 10, 1940, pages 481–482.

New laboratories of High Duty Alloys, Ltd., to be used in light-alloy research are described, including: spectrographic, and corrosion and protection, X-ray crystallographic, damping, colorimetric, experimental-testing, metallographical, chemical, mechanical-testing and radiographic laboratories, instrument workshop, heat-treatment department and rolling mill, and experimental foundry. *Engineer*, May 10, 1940, page 439.

Technique in Industrial Radiography. H. R. Isenburger. Photographic method, which is described for determining the depth of the flaw in castings, is based on a modification of stereoscopy or triangulation. Problem of testing metal castings and parts for defects which might weaken the structure is discussed and a number of methods for surmounting the usual difficulties are explained. In the double-exposure technique reference marks are placed on the front and back surfaces of the material undergoing tests, and two exposures are made, both with the target at the same distance from the outer surface but from slightly different angles. Defects can be localized more easily, quickly, and economically than by the stereoscopic method. Discussion also covers: a method of determining plate thickness of objects not readily accessible; a method of obtaining exographs of an object varied in thickness or in X-ray opacity; and special high-atomic-weight filter sets to be used with various thicknesses of steel to eliminate the X-ray scattering. *Photo Technique*, June, 1940, pages 62–65, 6 illus., 3 tables.

Welding and Brazing

The Fundamental Nature of Welding. D. E. Babcock and S. A. Braley. Effects of various alloying elements, fluxes, and slags in arc-welding rods. State of both physical and chemical research in this field, as presented in published literature now available, is reviewed, covering: concentration of carbon and manganese, silicon, and aluminum; solubility of nitrogen in liquid iron; phosphorus and sulfur; and effect of nitrogen. Physical properties of molten iron are considered.

Since the droplet of metal and the mechanism of transfer have been demonstrated to be a mixed liquid and vapor transfer of metal and slag, conditions involved in the gain or less in chemical composition of the weld metal during deposition should be more readily interpreted. Effects of surface tension of the metals, slag viscosity, drop formation, and coalescence should all be apparent in the results obtained in variation of welding conditions.

Apparatus used and experimental test procedure and results obtained in an investigation are described. Final comparisons of chemical analyses of rods used, slag obtained, and the weld metal were made to determine what changes had occurred during welding, and what, if any, equilibrium conditions may have existed in the slag-metal system formed. *Welding Jour., Weld. Res. Sup.*, June, 1940, pages 222s–230s, 9 illus., 7 tables.

Plastics

Wood Cements for Aircraft Construction. Joints in which the new hot hardener in powder form, introduced by British Industrial Plastics, Ltd., is used can be made to comply with the Air Ministry Specification 4V3. This demands a minimum shear strength of 200 lb./sq.in. dry and 100 lb./sq.in. when the wood is tested wet after being boiled for three hours. By using Beetle Cement W and Hot Hardener 12, plywood can be made to return a figure of more than 300 lb./sq.in. dry and over 200 lb./sq.in. after boiling. Beetle Cement A, recently evolved to meet the special requirements of the aircraft and constructional wood-working industries, is a cold-setting urea-formaldehyde cement that can be used to make joints between wooden surfaces that are not in absolute contact. Strong joints can be made with a cement line as thick as 0.020 in. Few details only of these products, and of joints made with Kaurit Glue W (now known as Beetle Cement W to distinguish it from the German product). *Aeroplane*, May 31, 1940, page 744.

A Letter from London. J. S. Trevor. By controlling the pH of the polymerization of the resin N. A. de Bruyne has been able to bridge gaps of as much as 0.020 in., and yet obtain joints as strong as those made between close-fitting wooden surfaces. Whereas in the case of ordinary urea-formaldehyde resin the solidified mass formed between the joints crazes badly due to physical changes taking place in the interior of the mass, with the new hardener now on the market the resin polymerizes to form a solid and perfectly homogeneous mass possessing the maximum strength. Use of the new hardener is said to speed up production. Table shows apparent shear stress and average for gaps of 0.020, 0.010, and 0.005 in. obtained in tests with the new hardener. Brief reference only in a short article on developments in the British plastics industry. *Modern Plastics*, May, 1940, page 46, 1 table.

Rubber

"Buna" Synthetic Rubber. E. Konrad. Properties of natural rubber as a material, synthetic methods for the production of rubber, and properties of Buna synthetic rubber are discussed in detail with references to properties of Duprene and Neoprene. Highest resistance to wear is shown by Perbunan, and resistance of Perbunan to oils is said to be superior to that of Duprene. Besides the development of rubber for tires, German research has been directed toward finding special types of synthetic rubber which will open new industrial applications and which will meet requirements which hitherto could not be fulfilled with natural rubber.

Tables are presented for the following: physical properties of natural rubber, Perbunan, Buna S, and methyl rubber W; ultimate strength in tension, elongation, and load at 300 per cent expansion, for natural rubber, Buna N, Buna S, Buna 125, and Buna 85 in four conditions (not aged, and after aging for 8, 16, and 32 days, respectively), indicating the superior aging qualities of Buna types; similar properties obtained by aging (at the same periods with oxygen under 21 at pressure at 60°C.) natural rubber, Buna N, Buna S, Buna 115, and Buna 85; heat resistance for samples heated in steam at 151°C., including ultimate strength in tension, elongation at rupture, load at 300 per cent expansion, Shore hardness, and rebound elasticity of natural rubber and Buna S untreated and treated for different periods of 5 to 25 days; and heat resistance for samples heated in hot air of 150°C. including similar properties for natural rubber and Buna S in the untreated and treated conditions for different periods of 12 to 72 hours. Translated from "Jahrbuch, 1938, der Deutschen Luftfahrt Forschung." *Royal Aeronautical Soc., Jour.*, May, 1940, pages 439–446, 1 illus., 4 tables.

Composite Elasticity of Rubber. H. Mark. Nature of rubber elasticity and the three different elementary processes taking place during the extension are considered, and elastic behavior of materials with flexible entangled chain molecules is explained. The stress-strain curve of rubber divided into three ranges of elasticity is illustrated with the properties of each range defined. By use of statistical considerations and under the assumption of a certain limited internal flexibility of the long chain molecules, it is concluded that a gaseous-like elasticity is obtained, which is described by the equations given, and that it seems to be the prominent mechanism during the first part of the extension curve. To be continued. *India Rubber World*, June 1, 1940, pages 41–45, 2 illus., 9 equations.

Silent Electrical Discharges on Rubber Solutions. L. Hock and H. Leber. Action of silent electrical discharges on solutions of natural rubber and of Buna were investigated in efforts to develop rubbers with greater heat resistance. Results given indicate the way in which electrical polymerization affects the properties of vulcanizates and appear promising. Translated from "Kolloid-Z," January. *India Rubber World*, June 1, 1940, page 71.

Meteorology

Meteorological Conditions Associated with Aircraft Lightning Discharges and Atmospherics. E. J. Minser, T.W.A. From a study of the records of lightning discharges to aircraft, experienced by Transcontinental and Western Air, Inc., between 1935 and 1939, the conclusions presented regarding the origin of the electrical charge and distribution with cloud mass are made. Majority of discharges occurred not in well-developed thunderstorms but in large cumulus clouds. All the characteristics of a cumulo-nimbus cloud were present, particularly precipitation forms, their distribution in the cloud and turbulence. Most striking similarity of conditions observed was in the temperature distribution and precipitation forms. Average temperature at flight level was 28°F., with only a few departures outside the 25° to 34°F. range. Precipitation form was predominantly rain and/or wet snow. Sequence of events culminating in a lightning discharge through the airplane is described, and a theory to explain the origin of the electrical charge in thunderstorms is offered. *Am. Meteorological Soc., Bul.*, May, 1940, pages 200–202, 2 illus.

A Design for a Geostrophic Wind Scale. C. V. Brown. A geostrophic wind scale may be constructed for any degree of latitude and for any distance between isobars by plotting the ordinates on a scale of log sine of latitude and the abscissa on a scale of map distance in miles. Resultant wind movement may then be plotted as sloping lines by connecting points for each 5° or 10° of latitude along the resultant map distance for each distance between isobars. Tables show six hourly resultant wind movements for construction of a geostrophic wind scale and distance between isobars when wind force is known. *Am. Meteorological Soc., Bul.*, May, 1940, pages 178–181, 1 illus., 2 tables.

Is Radiative Cloud Cooling a Significant Phenomenon in the Atmosphere? W. M. Elsasser. From the table given one can readily, by means of the

formula, compute the radiative cooling of any cloud (provided there is only a single cloud sheet; the case of multiple cloud layers must here be excluded). Values of net upward fluxes at the base and top of the cloud can be obtained from the table by interpolation for any height of the cloud top and base. Net outflow of heat from a cloud is of the order of 30 calories in 3 hours. *Am. Meteorological Soc., Bul.*, May, 1940, pages 202–205, 1 table, equations.

The Tail Method of Obtaining Data on Winds Aloft. E. F. Corwin. Need for a method of making more accurate single theodolite pilot balloon observations has long been felt. Errors involved in assuming a constant ascensional rate, especially in mountainous territory, are at times quite appreciable and thermal currents also help to produce erroneous readings. British tail method of pilot balloon observation is explained and the tail-intercept method developed by authors is described which used a balloon for a tail, rather than the cardboard, that was inflated just enough to counterbalance the weight of the rubber. In the investigation described, ascensional rates from 100 to 200 m./min. were obtained with No. 30 Darvex balloons, and ascensional rates of 200 to 300 m./min. with No. 100 Darvex balloons.

The tail-intercept method needs a tremendous amount of checking under widely varying conditions, before it would be safe to say what the average degree of accuracy of the method is, but whenever pilot balloon ascents are influenced by either slope or thermal currents, or especially by bad terrain effect of mountainous territory, the method is much more accurate. Tail-intercept method also has other advantage over the two theodolite method. *Am. Meteorological Soc., Bul.*, May, 1940, pages 184–189, 11 illus.

Fuels and Lubricants

Automotive Engineers Asked to State Future Fuel Needs. It was the purpose of refinery chemists attending the thirty-fifth meeting of the S.A.E. to ask the designers of motor-car and airplane engines what kinds of fuel are preferred, and how much more a new fuel could cost over ordinary gasoline before it would be considered uneconomical. Refining industry has reached a position in its research and commercial program of catalytic polymerization, catalytic alkylation, and catalytic cracking, etc., to permit it to manufacture almost any kind of hydrocarbon from crude oil. Review of papers presented relating to catalytic work, engine heat losses, safety fuels, and motor lubricants, and discussions. *Oil & Gas Jour.*, June 13, 1940, pages 36, 40.

Fundamentals of Solvent Refining Operation. E. W. Gard and E. G. Ragatz. More important characteristics of an ideal solvent; features which the more complicated solvent-extraction operation has in common with rectification; definitions of yield efficiency, extraction ratio, and selectivity ratio; increased yields with increased solvent ratios; optimum point of feed introduction; effect of treater temperature, phenol *versus* SO_2 and SO_2-C_6H_6 treatment of mixed base dewaxed distillates; and relationship between raffinate quality and solvent requirements. American Chemical Society paper. *Oil & Gas Jour.*, June 6, 1940, pages 49–50, 53, 5 illus.

Engine Design and Research

An Analysis of Certain Characteristics of a Kadenacy Engine. S. J. Davies. First issue—Motion of the air for combustion to the engine cylinder and evacuation of the exhaust gases from the cylinder later in the cycle are considered. Engine tested was an opposed-piston two-stroke oil engine, the lower piston working directly through a connecting rod on the crankshaft and controlling the exhaust ports, while the upper piston was connected to the crankshaft by return connecting rods and controlled the admission ports. Special observations were made of pressure variations in the admission passages, in the cylinder and in the exhaust system. In order to have the highest possible degree of accuracy the Sunbury cathode-ray indicator was combined with the type of balanced disc valve used in calibrating, and recorded values were obtained from directly calibrated readings of pressure.

Second issue—A further factor taken into account is that, of the air charge taken in, a portion may pass through to the exhaust without taking part in the combustion. This is to be expected from the high value of the volumetric efficiency measured, but other evidence is presented in curves which show the mean temperatures observed by placing a mercury thermometer in the exhaust pipe at four measuring points. Basis on which the transformation of the energy of the gases in the cylinder into the kinetic energy of the gases passing through the exhaust port should be considered is discussed, and Magg's treatment is shown to be incomplete. Using his own experimental data and considering, from instant to instant, the energy still remaining in the cylinder and that conveyed away by the gases issuing from the exhaust port, the author calculates the pressures, temperatures, and velocities necessary for continued equilibrium between the energy in the cylinder and that lost externally. *Engineering*, May 24 and June 7, 1940, pages 515–517 and 557–559, 11 illus., many equations.

The Development of Sodium Cooling of Exhaust Valves. History of developments in exhaust-valve cooling methods is traced and work of S. D. Heron at McCook and Wright Fields on the sodium cooling of these valves is described. *Automotive Industries*, May 1, 1940, pages 417–418.

Exhaust-Pipe Effects in a Single-Cylinder Four-Stroke Engine. G. F Mucklow. Fluctuations of pressure, due to piston motion on the exhaust stroke and occurring in the exhaust pipe of a single-cylinder four-stroke engine, were investigated in the experiments described. Indicator diagrams of exhaust-port and cylinder pressures were taken, and measurements of air consumption were recorded with the use of exhaust pipes of three different diameters at three standard engine speeds, the exhaust-pipe length being varied over a wide range in each case. In the light of data thus obtained, effects on air consumption of progressive alterations in valve timing were studied under known conditions of exhaust-port pressure. Further trials were then carried out in which the valve timing giving the maximum air consumption was determined for the full range of conditions of speed and exhaust-pipe dimensions.

Experimental results are discussed, and a method is derived by which the pressures in the exhaust port throughout the cycle may be obtained from theoretical considerations. Method is also directly applicable to induction-pipe conditions. Testing apparatus, which was used on a Rolls-Royce cylinder, and experimental procedure are described. *Inst. Mechanical Engrs., Jour. & Proc.*, May, 1940, pages 109–127, 30 illus., 6 tables, many equations.

The Mounting of Aero Engines with Special Reference to Rubber and Buna Material. B. Steinborn, Continental Rubber Compagnie, G.m.b.H. Fundamental conditions to be considered in using rubber for the mounting of aircraft engines. Figures for the permissible loads and hints for the design of rubber components are given with special reference to the use of Buna. Some constructional features are discussed as an explanation of the advice tendered to the designer.

For the design of mounting blocks, it is recommended that, in view of mold costs and interchangeability, simple parts should have the preference, sharp edges should be avoided at the metal parts, and all corners should be chamfered. It is advantageous to use thin steel plates which allow for interchangeability and adjustment. Within the rubber the strain should be uniformly distributed in order to secure better resistance against endurance fractures. Arrangements liable to slip as soon as the rubber is being deformed should be avoided as far as possible. An interlocking catch has to be provided at the damping elements, which automatically comes into action as soon as the rubber fails as a supporting and connecting medium. Special consideration should be given to the behavior of rubber under the influence of differences in temperature. For the metal bonding of vibration-absorbing elements, the heavier of the light alloys such as duralumin and silumin are preferred although the best bonding values will be obtained with steel or iron disc plates. Translated from "Jahrbuch, 1938, der Deutschen Luftfahrt Forschung." *Royal Aeronautical Soc., Jour.*, May, 1940, pages 447–450, 6 illus.

The Process of Combustion in Spark Ignition Engines. W. T. David. Turbulence set up during the process of combustion is given as an explanation for the increase in flame travel. Some of the older theories which have been shown as untenable by flame photographs are reviewed and the combustion process is pictured with some explanations. The case is considered of flame propagation through a stagnant inflammable gaseous mixture contained in a closed spherical vessel after central ignition. The problem of why subsequent stages of combustion are so markedly influenced by turbulence, whereas the initial stages of combustion are quite uninfluenced by it, is discussed, the answer appearing to be that the mode of flame propagation during the initial combustion is very different from that during the subsequent combustion.

It is shown that with the exception of centrally initiated explosions within spherical vessels, turbulence is always set up during the process of combustion even in mixtures originally stagnant, thus speeding up the later stages of combustion. Another experiment is described in which it was found from a flame photographic record that flame travel was more rapid through the half of the tube containing metal rods than through the other half, the expanding flame gases causing relative motion between the unburnt gases ahead and the surface of the metal rods, thus initiating a turbulent or eddying motion to be set up resulting in more rapid flame travel. *Engineer*, June 7, 1940, pages 509–510, 6 illus.

Radiator Research in the U.S.S.R. S. G. Litkin. Installation of a duct in an airplane wing is not only harmless in regard to turbulence, but even improves the flow over the wing especially at large angles of incidence where lift coefficient is increased by the duct. A radiator efficiency figure is developed which is used to compare the usefulness of the various combinations tested. The value of $\epsilon = a/\Delta C_D$ (a = ratio of airspeed through radiator block to that outside the installation, and ΔC_D = total drag of radiator installation) wholly characterizes the quality or efficiency of the radiator installation from the point of view of the consumption of power at higher speeds of the airplane. Most favorable radiator installations are those with small values of a unless the decrease in a is followed by large additional losses. Of the variation of ducts in the wing, the most favorable is that with the inlet at the leading edge and the outlet on the upper surface of the wing at a distance of 50 per cent of the chord and having several guide vanes. Replacement of underslung radiators by radiators in the wing has shown considerable advantages with regard to their maintenance and durability.

Airfoil section selected for the model tests described was a 20 per cent thick one called ANT-6. Three aspects considered include: efficiency or quality of the duct; effect of the duct and flow through it on the polar of the wing; and volume of air passing through the duct. Equations are developed for duct losses.

Flight tests, also described, were made on a twin-engined low-wing type (apparently the TB-3) having a thick wing and engines in line with the leading edge. Engines were M-17s (B.M.W.VI water-cooled 12-cylinder vee 600-hp. unsupercharged) and driving propellers turning in the same direction. Radiators were installed outboard of each engine in the wing. Use of these wing radiators increased airplane speed by 2 per cent which corresponds to a 6 per cent decrease in drag. Flow over the wing behind the radiator outlet was shown to be smoother (in a glide) than that over the rest of the wing.

Comments on the article, made from a British point of view, point out, among other things, "It appears to engineers in this country that the main characteristic of Russian aeronautical research is that it is never applied to Russian aeroplanes. . . . But in the last three years there has been no sign that any serious application of this work has been made." C.A.H.I., Moscow, Technical Note No. 147, 1937, translated by Rolls Royce, Ltd., and available as British Air Ministry Translation No. 970. *Aircraft Engg.*, May, 1940, pages 133–136, 146, 15 illus., many equations.

Ceramic Insulators for Spark Plugs. F. H. Riddle. Paper presented at the Annual Meeting and previously abstracted from preprint. (See page 316, May issue of the Journal.) *S.A.E. Jour. (Trans.)*, June, 1940, pages 236–240, 9 illus., 5 tables.

Fuel Injection in Oil Engines in Relation to Combustion. G. W. A. Green. Design of fuel-injection equipment is discussed with recommendations, including: hole-type nozzles; pintle variable-orifice nozzle; differential needle valves for both types of nozzles and needle-lift diagrams; importance of chattering needles; "delay" or "restricting" atomizers; atomizer designed to have inherent stability; effect on shape of delivery-pipe pressure diagram of a special type of "unloading" delivery valve allowing a certain amount of return flow of fuel from the delivery pipe when spill occurs; delivery pipe between pump and atomizer, and the fuel velocity in the pipe for which the author has found values up to 3000 cm./sec. satisfactory. To be continued. Institution of Mechanical Engineers paper. *Engineering*, June 14, 1940, pages 592–593, 3 illus., 1 table.

Graphical Analysis of Thermal Stresses. D. White. By the method described stresses and distortion resulting from temperature differences in any structure can be determined, whether heat is from fire, welding, friction, or any source. Accuracy is dependent upon the knowledge of the properties of the material. If temperature distribution and the thermal and mechanical properties are known, the analysis is exact.

Example chosen is a 44-in. diameter brake drum made of two materials of different strengths, and shows the designer how to design this part to meet the service conditions with the aid of a few simple tests. If applied to welding the stresses can be determined either parallel to, or across, the weld in the same manner as the analysis for the brake drum. New brake drum expands 0.088 in. and then contracts 0.039 in. below the original size the first time it is used. The steel at the braking surface is repeatedly heated above the critical temperature and this results in great local deformation as the temperature crosses the hump in the expansion curve. Steel becomes much softened at the high temperature, and choice of material should be based on the high-temperature properties and not on those at room temperature. *Welding Jour., Weld. Res. Sup.*, June, 1940, pages 231s–238s, 15 illus., 3 tables, many equations.

Kinematic and Dynamic Study of a New Connecting Rod for Engines Having Axial Cylinders. L. Poggi. Study of connecting rods for the transmission of motion between the rotating shaft and one or more pistons

operating in cylinders with the axis parallel to the engine shaft is presented. Mechanism is described and the kinematic operation is analyzed, some relation being found that should be satisfactory as the motions of the various pistons are followed in the desired phase. After the selection of a suitable system of reduced masses, the various harmonics of the forces and of the moments of inertia due to the various parts, and their resulting values are calculated. Conditions necessary for the balancing of the forces and of the moments of the first order are deduced. In the appendix calculations for a concrete case are developed. *L'Aerotecnica*, May, 1940, pages 374–397, 2 illus., 37 equations.

Progress in Light Aircraft Engines. C. F. Bachle, Continental Motors Corp. Introduction of fuel injection in light aircraft engines, replacing carburetion, is considered the major development of last year. Injector developed by Continental Motors Corporation in conjunction with the Fuel Injection Corporation, consists of two constant-stroke pump plungers having combined reciprocating and turning motion, the latter motion permitting each plunger to serve two cylinders. Outstanding advantage of fuel injection is the positive prevention of ice in the induction system without use of an air heater or manifold jacket. Power at altitudes is higher, and there is greater assurance of uniform mixture distribution under all operating conditions. A detailed description of this equipment and test results are presented.

Other developments and refinements made to boost the output of light aircraft engines are discussed including cylinder-head design, exhaust valves and seats, pistons and rings, and valve mechanisms. (Preprint of paper available.) *S.A.E. Jour. (Trans.)*, June, 1940, pages 243–249, 16 illus.

Shortcomings of Mica Insulation for Aviation Spark Plugs. V. Cronstedt. Paper presented at the Annual Meeting and previously abstracted from preprint. (See page 316, May issue of the Journal.) *S.A.E. Jour. (Trans.)*, June, 1940, pages 233–235, 242, 2 illus.

The Two-Stroke Aero Engine. P. F. Martinuzzi. Advantages and drawbacks of the two-stroke gasoline aircraft engine, and ways in which direct gasoline injection helps. Qualities seem to indicate the two-stroke engine as particularly suitable for fighters, also owing to its fitness for altitude work. Good take-off power should be useful for flying boats. "Relatively low m.e.p. of the two-stroke engine is not a disadvantage; on the contrary. A low m.e.p. implies low mechanical stresses and a lower supercharge ratio. This means that the full rated power of a two-stroke engine can be obtained with a fuel of relatively low octane number. . . . Besides, as the normal m.e.p. must be kept low, there is a wide margin for a temporary power increase for the take-off; wider than in a four-stroke engine." The most likely aircraft two-stroke engine will have uniflow scavenge with the inlet near B.D.C. and exhaust in the head. A very efficient and somewhat large supercharger is vital and the two-stroke engine will therefore very probably be a liquid-cooled vee type.

General layout of the engine, the inverted-vee type, and the shorter exhaust period possible are discussed. Influence of two-stroke operation on the main engine components is considered in detail including: cylinder head and liner; exhaust valves; pistons and piston-temperature problems; piston and connecting-rod length; scavenging and supercharging problems; turbulence question; power saved; and sleeve-valve control. *Flight, Aircraft Engr. Sup.*, May 30, 1940, pages 17–21, 4 illus.

Turbo Superchargers. F. Umpleby. Port period and timing lines of turbo superchargers are taken up. The ballistic-velocity turbine is cooled by two airstreams, one from the induction side of the engine as in the Buechi and one drawn over the rim of the wheel by the exhauster blades. Two-stage compressors are discussed. A simple form of exhaust control for use with the ballistic-velocity type of supercharger, designed and patented by the author, is described. Valve which may be mechanically or automatically operated is used to divert the whole or part of the exhaust to a figure-of-eight device. A simple two-stroke compression-ignition end-to-end scavenge engine without valves and arranged for horizontal mounting is shown in a drawing. In control of the supercharged engine, the figure-of-eight acts in combination with the turbo-exhauster section of the turbine at low altitude. As altitude increases, the figure-of-eight is gradually cut out and the turbo-exhauster takes full control. Another method of altitude control is referred to.

By these methods the author has attempted to provide a solution to the problem of the simple, powerful and reliable aero engine able to operate at high or moderate altitudes. Such an engine is considered which could operate on volatile liquid fuel, either by fuel injection with spark ignition or on the "pure-air rich-mixture sandwich" system, or on high-flashpoint fuels by compression ignition. Engine for high-altitude work described comprises six common combustion-chamber cylinders, without valves, in two opposed rams of three, with a total capacity of 4.2 liters. Power output of 336 b.hp. at 3700 r.p..n. with 2½ lb./sq.in. of supercharge may be expected. Figures are given which might be obtained with such an engine. Continued. *Flight, Aircraft Engr. Sup.*, May 30, 1940, pages 22–23, 3 illus.

Engine, Fuel and Lubricant Testing

The Wear-Load Characteristic of the Four-Ball Test with Various Lubricants. R. Schnurmann. Wear-load characteristic can be regarded as a guide for the selection of suitable gear lubricants for various mating materials and conditions of load and speed. Dielectric breakdown strength is one important property of a gear lubricant, if it is considered in connection with the oxidizing properties of the lubricants on the mating surfaces. Oxidation may be beneficial within a certain range of loads, where it contributes to low continuous wear, as in such combinations as a steel worm and a bronze wormwheel, where transfer of fine oxidized steel particles may prevent the pick-up of coarse bronze particles by the steel worm which would lead to scoring and rapid failure.

The four-ball test imitates the "lubricating wedge" of a gear and seems to be a suitable apparatus for establishing wear-load characteristics, but its results do not prove the existence of a definite breakdown load of a lubricant. Comprehensive physical interpretation of lubricant tests has so far been impeded by certain unwarranted assumptions such as the existence of a "breakdown" load of gear lubrication and of a "seizure characteristic" of the friction elements. These characteristics, the four-ball test, oxidizing and dielectric properties and thinning out of a liquid film to a monomolecular layer are discussed. *Engineering*, June 7, 1940, pages 567–568, 1 illus.

Ranger Engine Test and Research Building. Outstanding feature of the new test and research building, which is to be ready for occupancy this month, is the arrangement of five test cells about a single soundproofed control room 90 ft. long. Space between the vertical soundproofed cooling-air stacks is utilized to provide an experimental room on the second floor, which is windowless, lined with sound-absorbent material and lighted with fluorescent lighting. Air compressors and air measuring and refrigerating equipment for carburetor air are installed in this room with controls for the apparatus located in the control room below. Equipment for testing engine accessories is also contained in this room upstairs. Brief description of building and drawing. *Aero Digest*, June, 1940, page 71, 2 illus.

Engines

Buda-Guiberson Diesel Engine. Buda-Guiberson A-1020 9-cylinder radial air-cooled Diesel engine is rated at 310 hp. at 2150 r.p.m. and is expected to develop 340 hp. at 2250 r.p.m. for take-off. Fuel consumption is 0.37 to 0.38 lb./hp.-hr. Using Texaco Diesel Chief fuel oil, such as used in tractors, the engine on a test flight consumed 13 gal. of fuel an hour. Tests show that at high altitudes the engine will maintain about 75 per cent of its full-load power. During its flight tests the airplane attained an altitude of 16,300 ft. and was still climbing at more than 500 ft./min. Bore 5.125 in. Stroke 5.5 in. Displacement 1021 cu.in. Weight (without propeller hub) 653 lb. Description. *Aero Digest*, June, 1940, page 53, 3 illus.

Ranger 12-Cylinder 450 Hp. Inverted Engine. Model SGV-770B-7 inverted-vee air-cooled engine, developed in cooperation with the Navy Bureau of Aeronautics, has a take-off and climb rating of 520 hp. at sea level and at 9600 ft. Very long description of cylinders, valve operation, crankcase, crankshaft and reduction gears, accessory drives, supercharing equipment, lubrication, and accessories. Bore 4 in. Stroke 5.125 in. Displacement 773 cu.in. Fuel consumption at normal rated power is 0.65 lb./hp.-hr. Characteristics and performance figures are given.

Second article describes the Ranger 6-440C 6-cylinder air-cooled inverted in-line direct-drive unsupercharged engine, including crankcase, connecting rods, pistons, cylinders, cylinder baffles, valve mechanisms, accessory driveshaft, lubrication, induction system, ignition, and accessory drives. *Aero Digest*, June, 1940, pages 72–73, 76–77, 162, 14 illus., 2 tables.

PARTS AND ACCESSORIES

Fuel Pump Developments to Meet Commercial Airline Service. J. M. Roth. Dependability of the slotted drive for fuel-pump rotors is compared with that of the spline drive and the two drives are also compared on the basis of horsepower that could be transmitted at 3000 r.p.m. New spline-driven fuel-pump rotor was developed by Pump Engineering Service Corporation. *Aero Digest*, June, 1940, pages 91, 162, 3 illus.

Engine Manufacture

Two Million Carburetors a Year. J. Geschelin. Plant of the Carter Carburetor Corporation, and its machine-shop, testing, and tooling equipment and methods are described. Two million carburetors a year are produced at the Carter plant where flexibility culminates in a bank of huge multiple-spindle drilling machines that are fully automatic and interchangeable. *Automotive Industries*, May 1, 1940, pages 404–411, 442, 18 illus.

Miscellaneous

Design for Living Portrayed at National Production Meeting. Account of S.A.E. meeting with abstracts of papers and discussion dealing with: cutting fluid recommendations; producing special surface finishes by honing; special problems in the production of aircraft engines; new method of testing and grading fine abrasives; and surface finish control in machine-shop practice. *S.A.E. Jour.*, June, 1940, pages 14–16, 24–25, 3 illus.

S.A.E. Summer Meeting Tuned to National Defense. Account of meeting and abstracts of papers dealing with: the part the S.A.E. will play in the national defense program; variation of engine output with altitude; better fuels for better engines; power per unit for gross weight; valve head and valve stem deposits; single-cylinder engine research for aviation; comparison of C.U.E. engines; design suggestions for safety; charging process of the two-stroke engine; properties of rubber in compression; aluminum in high-speed engines; wear-resisting coatings; load capacities of bearing surfaces; riding comfort and cushions; weight and cost of body frames; high-flash-point aviation fuels; high-volatility aviation fuel; analysis of engine-combustion data; testing oils in small engines; oil and fuel for heavy-duty engines; and continuous measurement of piston temperatures. *Automotive Industries*, June 15, 1940, pages 543–548, 563–574, 21 illus.

Aircraft Radio

Radio in the European War. H. W. Roberts. Parts played by radio in offensive operations, especially during a "Blitzkrieg," are summarized. An important use for aircraft radio direction finders is in bombardment operations against remote objectives, and radio facsimile apparatus is an important adjunct to observation and reconnaissance aircraft. Latest adjunct to observation work, not yet entirely out of experimental stage, is the television camera carried on board the airplane, transmitting vertical and oblique views of the battle terrain for projection on a large screen at headquarters. The radio altimeter and the gyromatic navigator (combining the functions of radio direction finder and directional gyro) should find speedy application to military aircraft needs, especially to bombardment.

Use of radio in defensive operations, radio interference, and the use of television receiving stations for the detection of aircraft beyond the range of the listening devices are briefly discussed. The absolute radio altimeter will probably soon find a new application in defense work: to measure constantly and automatically the height of enemy aircraft above the ground, with the radiation directed upward toward the airplane instead of downward, as in aircraft installation. *Aero Digest*, June, 1940, pages 51–52, 3 illus.

Aero Radio Digest. RCA Model AVR-7H aircraft receiver. Aerovoice Airguide two-way communication and navigation system for private flyers. Bendix Type MR-22C compact antenna coupling transformer. Western Electric Model 32-A UHF aircraft radio receiver selected for use on the principal airlines. Western Electric airport public-address system for the dissemination of information on flight arrivals and departures which has been installed at LaGuardia Field, New York. Lear Model ADF-8 station-seeking automatic radio direction finder. *Aero Digest*, June, 1940, pages 146, 149, 7 illus.

F. M.—What It Is and What It May Mean in Aviation Radio. D. Fink. Frequency modulation is described in detail and its advantages for aircraft are pointed out. To be continued. *Aviation*, June, 1940, pages 46–47, 124, 3 illus.

Learadio—Its Factory and Facilities. W. P. Lear. Manufacturing facilities of the new factory at Dayton Municipal Airport used in the production of 25 distinct types of aircraft radio apparatus. *Aero Digest*, June, 1940, pages 81, 96, 8 illus.

U. H. F. W. E. Jackson. Radioteletype and radiotelephone ground-to-ground and ground-to-aircraft ultra-high-frequency apparatus is described. *Aviation*, June, 1940, page 63, 2 illus.